

**Leavenworth National Fish Hatchery
U.S. Fish and Wildlife Service
Annual Flow Monitoring Report
Water Year 2012**

July 19, 2013

In accordance with

State of Washington
Department of Ecology
Water Quality Program

**EPA CWA 401 Certification Order No. 7192
Specific Conditions Requirements
B.1.c.i. Flow Monitoring in the Historical and Hatchery Channels
B.1.c.ii. Flow Monitoring in Snow Lakes and Snow Creek
B.6.a.i. & ii. Water Use and Temperature in LNFH Operations**

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INTRODUCTION

The Leavenworth National Fish Hatchery (LNFH) is located on Icicle Creek, a tributary to the Wenatchee River, at river mile (RM) 3.0 near Leavenworth, Washington. LNFH operates under the authority of the Grand Coulee Fish Maintenance Project, April 3, 1937 and Mitchell Act (52 Stat. 345), May 11, 1938. The goal of the hatchery is to assist in the mitigation for fish production loss associated with the construction and operation of Grand Coulee Dam. Currently, LNFH's production goal is 1.2 million spring Chinook salmon. Also, LNFH supports the Yakama Nation's Coho Reintroduction Project by providing hatchery facilities for part of its expanded coho salmon production program. The LNFH's water delivery system consists of five major components and conveyance systems: (1) intake and pipeline; (2) the Snow/Nada Lake Basin supplementation water supply reservoirs; (3) the well system on LNFH property; 4) water discharge facilities; and 5) structures 2 and 5.

In January 2008, the U.S. Fish and Wildlife Service (Service) requested a Clean Water Act (CWA) Section 401 Certification from the Washington State Department of Ecology (Ecology) for a 2005 U.S. Environmental Protection Agency (EPA) National Pollution Discharge Elimination System (NPDES) permit application for the LNFH. Ecology issued a CWA Section 401 Certification Order 7192 (Order) in January 2010. The terms of the Order require a continuous monitoring plan and annual reporting for Snow Lakes and Snow Creek (Order section B.1.c.ii.) and the hatchery channel and historical channel (Order section B.1.c.i.). The Service submitted monitoring plans to Ecology in April 2010 and Ecology approved in September 2010. In addition, the terms of the Order (section B.6.a.i. & ii.) require continuous monitoring and annual reporting of flow from groundwater and surface water inputs to the LNFH, discharges from the LNFH to Icicle Creek, and comparison of temperature from flow inputs to the flow outputs by using a flow-weighted averaging technique. This report provides the monitoring results required by the Order, the second monitoring report produced by the Service under Order 7192.

LNFH submitted a new NPDES permit application to the EPA on October 24, 2011 as substantial changes to hatchery operations have occurred since 2005. On October 26, 2011, LNFH requested a new CWA Section 401 Certification from Ecology to be associated with the new NPDES application. Currently, LNFH is fulfilling the requirements of the January 2010 Order 7192 until a new CWA Section 401 Certification Order is developed.

SITE DESCRIPTIONS AND MEASUREMENT METHODS

To quantify the amount of water flowing in the historical channel and hatchery channel of Icicle Creek, the Service proposed initiating surface water monitoring at two locations on the LNFH's property (Table 1, Figure 1); Historical Channel at Structure 2 and Hatchery Channel at Spillway. To quantify the amount of water released from Snow Lake into Icicle Creek, the Service proposed initiating surface water monitoring at two locations in the Snow Creek drainage (Table 1, Figure 2); Snow Lakes Outlet and Snow Creek Mouth. Once Ecology accepted the proposals, the Service implemented the monitoring plans as soon as possible. To quantify the amount of water and temperature of water input and output from the LNFH, the Service implemented monitoring at seven production well sites, one site for inflow, and two sites for outflow from the LNFH. The production well sites are Production Well No. 1 - 7 (PW-1-7), the LNFH inflow site is LNFH Icicle Creek Diversion, and the LNFH outflow sites are LNFH Discharge at Fish Ladder (Outfall 1) and LNFH Discharge at Abatement Pond (Outfall 2).

Table 1. List of site numbers, names, parameters, measuring device, and data inventory.

Site Number	Site Name	Parameter	Measuring Device	Continuous Data Inventory for Water Year 2012
322501	<i>LNFH Discharge at Fish Ladder (Outfall 1)</i>	gage height	ultrasonic level transducer	Oct 1 - Sep 30
		discharge	artificial control - flume	Oct 1 - Sep 30
		water temperature	thermistor	Oct 1 - Sep 30
322502	<i>LNFH Discharge at Abatement Pond (Outfall 2)</i>	gage height	staff gage	Oct 1 - Sep 30
		discharge	artificial control - weir	Oct 1 - Sep 30
		water temperature	thermistor	Oct 1 - Sep 30
322503	<i>Snow Creek at Mouth</i>	gage height	float and shaft encoder	Oct 1 - Sep 30
		discharge	artificial control - weir	Oct 1 - Sep 30
322506	<i>Snow Lake Outlet</i>	volume	calculated	Oct 1 - Sep 30
		discharge	artificial control - pipe valve	Oct 1 - Sep 30
		gage height	pressure transducer	Oct 1 - Sep 30
322508	<i>Production Well No. 1 (PW-1)</i>	well level	pressure transducer	Oct 1 - Sep 30
		well discharge	In-line meter	Oct 1 - Sep 30
		water temperature	thermistor	Oct 1 - Sep 30
322517	<i>Production Well No. 2 (PW-2)</i>	well level	pressure transducer	Oct 1 - Sep 30
		well discharge	In-line meter	Oct 1 - Sep 30
		water temperature	thermistor	Oct 1 - Sep 30
322510	<i>Production Well No. 3 (PW-3)</i>	well level	pressure transducer	Oct 1 - Sep 30
		well discharge	In-line meter	Oct 1 - Sep 30
		water temperature	thermistor	Oct 1 - Sep 30
322511	<i>Production Well No. 4 (PW-4)</i>	well level	pressure transducer	Oct 1 - Mar 27*
		well discharge	In-line meter	Oct 1 - Mar 27*
		water temperature	thermistor	Oct 1 - Mar 27*
322512	<i>Production Well No. 5 (PW-5)</i>	well level	pressure transducer	Oct 1 - Sep 30
		well discharge	In-line meter	Oct 1 - Sep 30
		water temperature	thermistor	Oct 1 - Sep 30
322513	<i>Production Well No. 6 (PW-6)</i>	well level	pressure transducer	Oct 1 - Sep 30

Site Number	Site Name	Parameter	Measuring Device	Continuous Data Inventory for Water Year 2012
322514	<i>Production Well No. 7 (PW-7)</i>	well discharge	In-line meter	Oct 1 - Sep 30
		water temperature	thermistor	Oct 1 - Sep 30
		well level	pressure transducer	Oct 1 - Mar 27*
322525	<i>Historical Channel at Structure 2</i>	well discharge	In-line meter	Oct 1 - Mar 27*
		water temperature	thermistor	Oct 1 - Mar 27*
		gauge height	pressure transducer/bubble gage	Oct 1 - Sep 30
322527	<i>Hatchery Channel at Spillway</i>	discharge	artificial control	Oct 1 - Sep 30
		gauge height	bubble gage	Oct 1 - Sep 30
322533	<i>LNFH Icicle Creek Diversion</i>	discharge	artificial control - weir	Oct 1 - Sep 30
		water temperature	thermistor	Oct 1 - Sep 30
		discharge	acoustic Doppler current profiler	Oct 1 - Sep 30

* Data inventory does not cover full year.

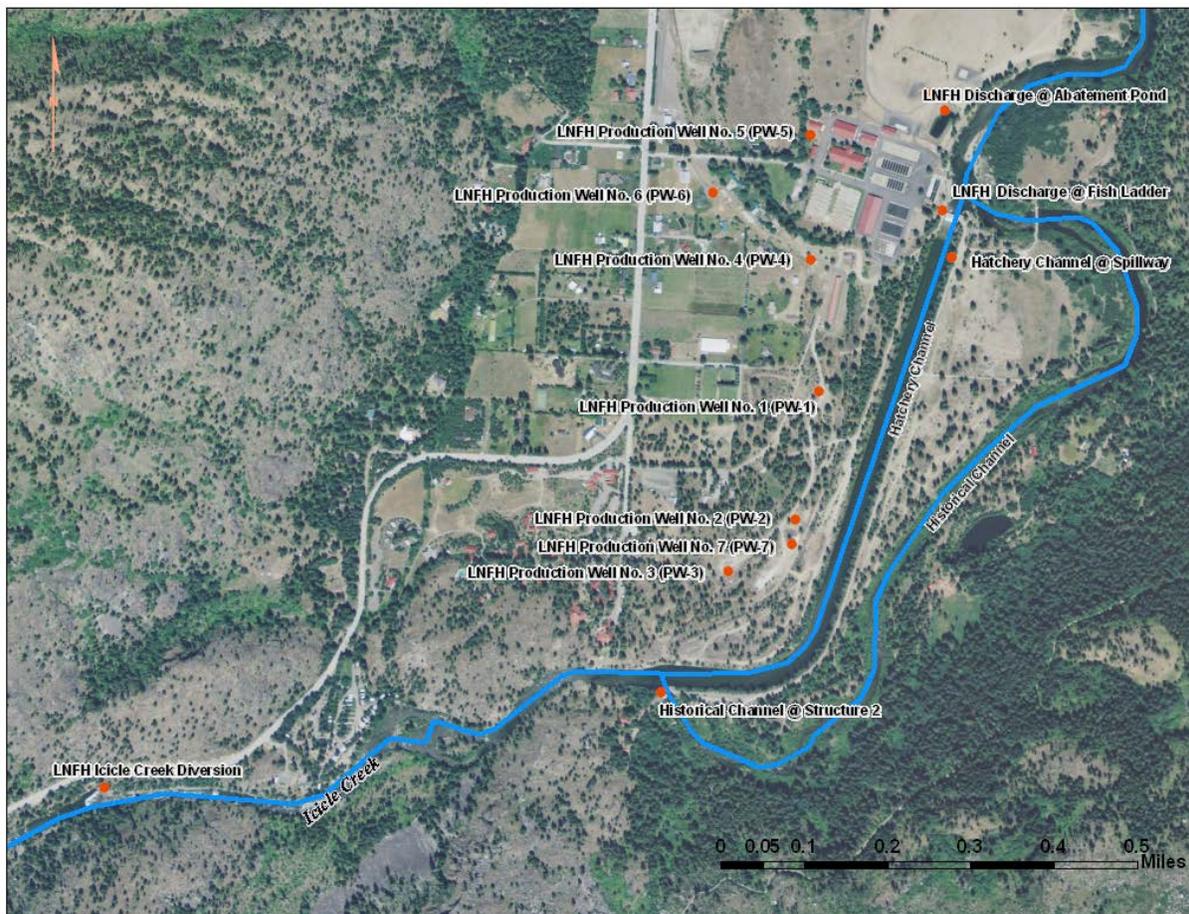


Figure 1. A map of water measurement sites near the LNFH. Orange dots denote the location of the measurement instrumentation.

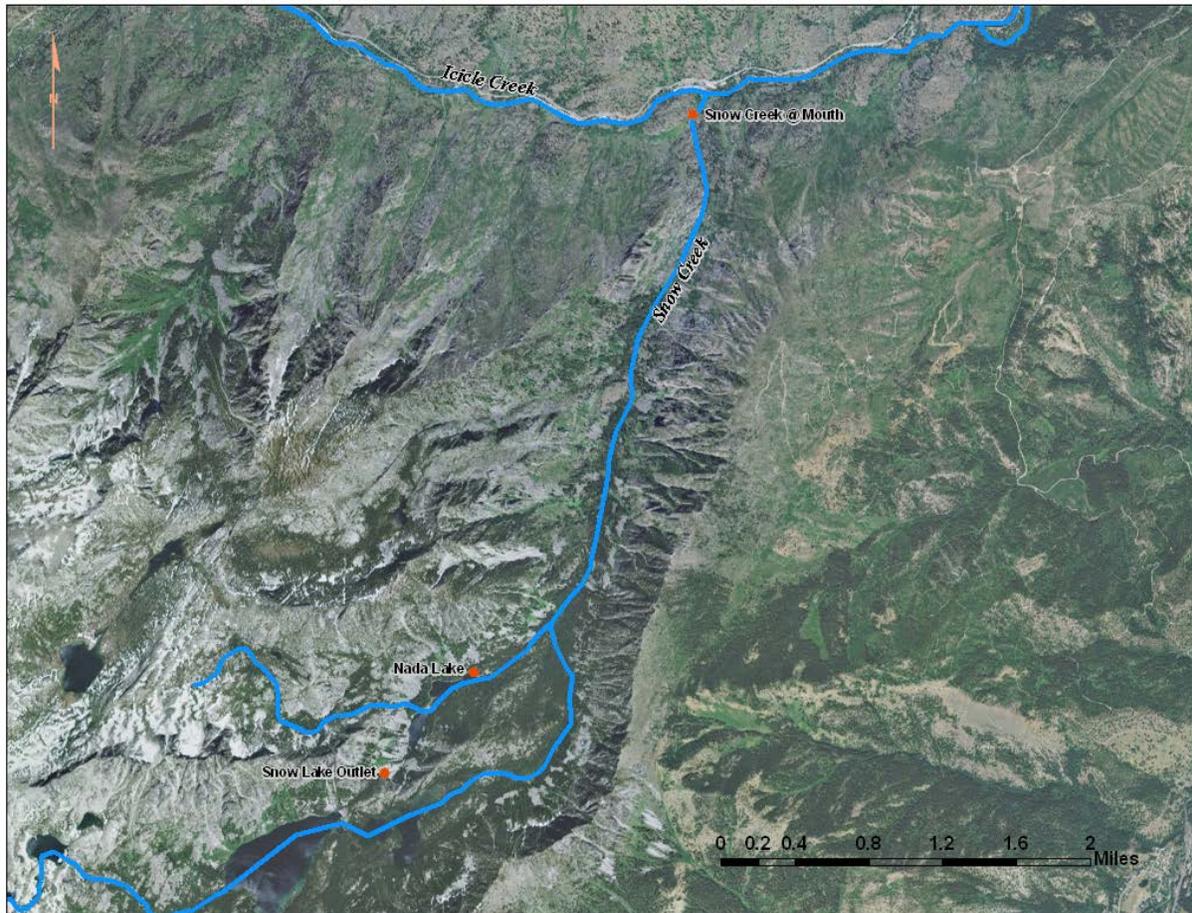


Figure 2. A map Snow Lakes and Snow Creek water measurement sites. Orange dots denote the location of the measurement instrumentation.

Historical Channel and Hatchery Channel

Historical Channel at Structure 2

A double radial gate (Structure 2) at the upstream end of the historical channel controls flow distribution between the historical channel and hatchery channel. When the radial gate is lowered down to water level and the opening is restricted, part or almost all of the flow is diverted into the Hatchery Channel depending on whether the gate is partially or fully closed. All of the flow cannot be diverted down the Hatchery Channel because a minimal amount of flow leaks past the radial gates down the Historical Channel of Icicle Creek. It is important to note that at 2.5 feet stage or higher the flow will back up in the Hatchery Channel even when the radial gate is opened fully. Sverdrup (2000) identified the equations for estimating discharge in the radial gate through a hydrologic and hydraulic analysis of the historical channel (Equation 1).

Equation 1. $Q = C * W * H^{1.5}$

Where: Q = discharge in cubic feet per second (cfs)*

W= width of the radial gate opening (16 feet)

H = height of the water surface above base of the Structure 2 (feet)

C = weir coefficient (2.8)

* Equation 1 applies to one of the structure’s gates. To determine flow through both gates multiply Equation 1 by two.

Equation 1 is only applicable when both radial gates are open and not in contact with the water surface.

Measurements in the historical channel downstream of Structure 2 confirm that Equation 1 provides a good estimate of flow through the structure (Table 2).

Table 2. Estimated and measured flow in the historical channel using Equation 1 when structure 2 gates are not in contact water surface.

Date	Height of Water (feet)	Estimated flow (cfs)	Measured flow (cfs)	Percent Difference
9/30/09	0.70	52	52.6	+1%
10/15/09	1.06	98	101	+3%

When the radial gates are lowered at or below water level then equation 1 does not apply. Under these conditions the following equation (2) (Sverdrup 2000) is used to estimate flow through Structure 2. To ensure accuracy of the use of the equation, both gates are lowered the same distance at the same time.

Equation 2. $Q = B * C * W * \sqrt{(2 * g) * H}$

Where: Q = discharge in cubic feet per second (cfs)*

B = size of the opening under the radial gate (feet)

H = height of water surface above the base of Structure 2 (feet)

C = coefficient of discharge determined empirically from measurements (0.5).

W = width of the radial gate opening (16 feet).

g = acceleration due to gravity (32.2 ft/s²)

* Equation 2 applies to one of the structure’s gates. To determine flow through both gates multiply Equation 2 by two.

Point measurements of discharge downstream of Structure 2 indicates Equation 2 is an effective measure of flow into the historical channel when the gates are partially open (Table 3).

Table 3. Estimated and measured flow in the historical channel using Equation 2 with gates at Structure 2 partially open.

Date	Opening (ft)	Height of Water (ft)	Estimated Flow (cfs)	Measured Flow (cfs)	Percent Difference
9/30/09	0.30	1.90	53	52	-2%
10/1/09	0.30	2.00	54	52	-4%
10/8/09	0.06	5.23	18	17.6	-2%
10/9/09	0.16	3.75	40	38	-5%
10/14/09	0.46	0.69	49	46	-6%

A wire weight gage mounted on the fence railing of Structure 2 measures the height of water above the Structure 2 spillway (Figure 3). The gage was set so that 0.0 feet equates to the top of the Structure 2 spillway crest. The maximum opening of the radial gate is 5 feet and limits the use of Equation 1 to water heights of 5 feet or less over the spillway crest. Water height measurements using this gage were applied to Equations 1 or 2 to quantify flow into the historical channel of Icicle Creek. The wire weight gage is located approximately 20 feet upstream of the spillway crest of Structure 2.

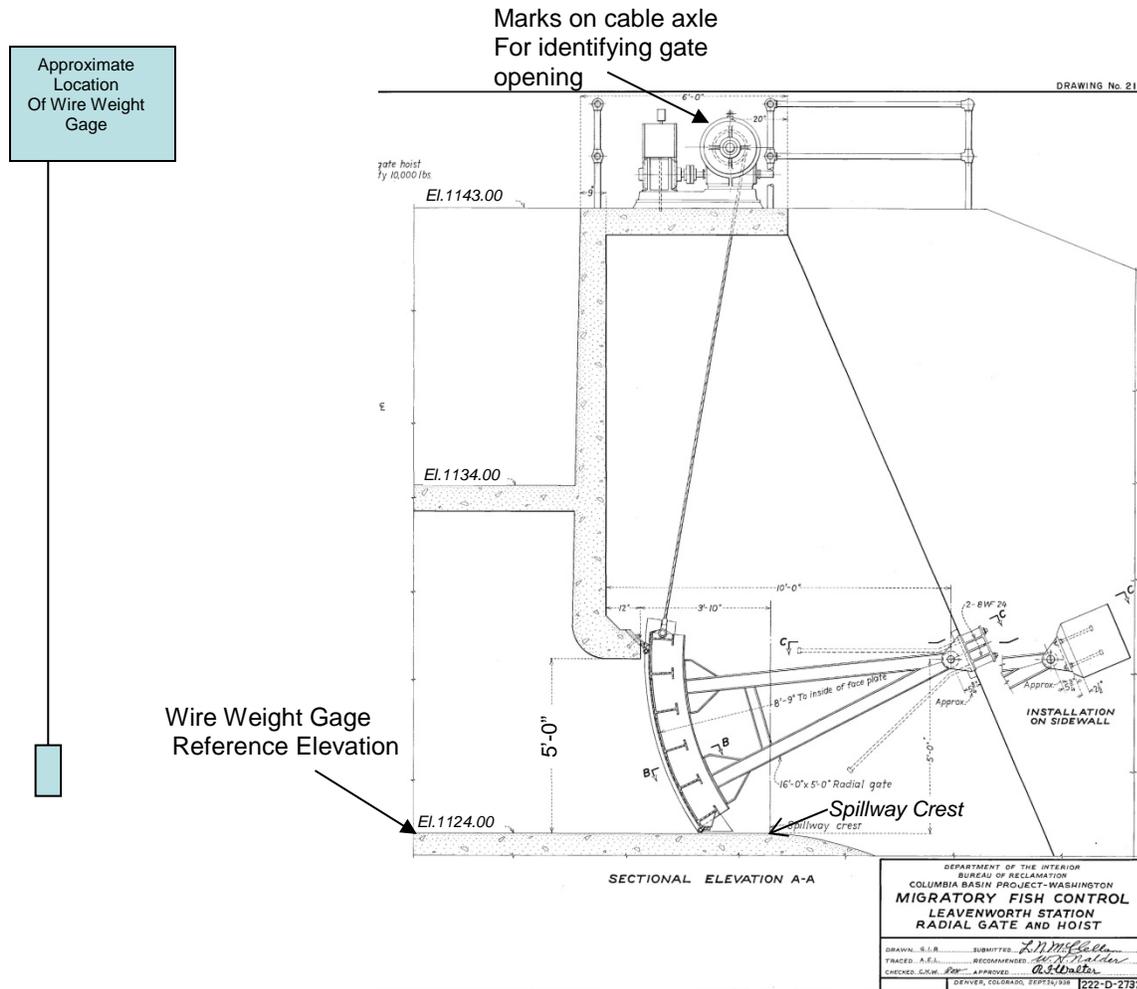


Figure 3. Cross section view of Structure 2 radial gate with approximate measurement locations. Location and size of wire weight gage not to scale.

To monitor water levels at the radial gate continuously, the Service mounted a 15 psi pressure transducer inside the pump well; a well inside the upstream bulkhead wall of Structure 2 that connects to the creek at the site of the wire weight gage. Beginning October 5, 2010, water levels recorded by the pressure transducer referenced the wire-weight gage. A bubbler system (non-submersible pressure transducer) replaced the pressure transducer on September 20, 2011. The datalogger recorded water levels at 15-minute intervals except from February 17, 2012 until March 7, 2012 when battery issues occurred.

The radial gate opening was set at 4.74 feet from the beginning of the water year until February 14, 2012 when the radial gate was lowered down to water level to divert water into the Hatchery Channel of Icicle Creek (table 4). The gate was kept lowered until February 29, 2012 when the gate was raised. The gate was kept open at

5 feet until September 6, 2012 when the gate was lowered again until September 19, 2012. Comparisons between the check flow measurements and the calculated flows using equation 2 indicate that the radial gate opening measurements were biased low, which is not congruent with the original comparisons in 2009 (table 3). To compensate for this discrepancy the calculated flow was shifted up to the level of the check measurements. Unfortunately, flow measurements were not conducted at every radial gate opening and the shift had to be estimated, or in some cases the radial gate opening used in the calculation was changed to a larger opening that resulted in a more representative flow calculation. Flow calculated when the radial gate was lowered is considered estimated.

Table 4. Historical Channel of Icicle Creek at Structure 2 radial gate openings in feet.

Date	Time	Radial Gate Opening (ft)
10/01/2011	12:00:00	4.74
02/14/2012	12:53:00	0.92
02/15/2012	10:30:00	0.43
02/17/2012	14:20:00	0.38
02/22/2012	09:00:00	0.42
02/27/2012	12:00:00	0.42
02/28/2012	13:30:00	0.55
02/29/2012	10:30:00	5.43
09/06/2012	08:45:00	0.07
09/19/2012	08:00:00	0.30
09/19/2012	11:30:00	5.46

Check measurements were completed with either the SonTek FlowTracker Handheld Acoustic Doppler Velocimeter (FlowTracker ADV) or the SonTek RiverSurveyor Acoustic Doppler Current Profiler (RiverSurveyor ADCP). The highest check flow measurement was made at a stage of 7.08 feet (1680 cfs) and flows calculated above this stage are estimated.

Hatchery Channel at Spillway

Water backs up and fills the hatchery channel under two conditions; 1) when natural stream flows are high enough to back-up at structure 2 and flow down the hatchery channel or 2) the gates at structure 2 are lowered to divert flow down the hatchery channel. The water level at structure 2 dictates the extent of water flowing into the hatchery channel or whether it flows over the 84-foot weir spillway at the end of the channel (figure 4). At low flows in Icicle Creek all the water flows down the historical channel and no water will be present in the hatchery channel. The elevation of the water surface in the hatchery channel was referenced to a staff gage mounted on the upstream edge of the spillway. Flow out of the hatchery channel was estimated using the following equation (3). Equation 3 was developed using the Bureau of Reclamation's WinFlume software (version 1.05.0029).

$$\text{Equation 3.} \quad Q = 274.4 * H^{1.587}$$

Where: Q = estimated discharge over the channel spillway (cfs)

H = height of water over the channel spillway

The original staff gage was installed in September 2009 (figure 4). The original staff gage elevation of 0.0 feet is equivalent to the top of the spillway. On September 20, 2011 a new staff gage was installed in the hatchery channel approximately 120 feet upstream of the spillway, in order to avoid drawdown effects near the spillway. The original staff gage offsets the new staff gage by 2.99 feet; where the original staff plate is 0 feet at the 2.99 feet mark on the newly installed staff plate. A bubbler gage was installed May 10, 2011 to record water levels at 15 minute intervals. After the installation of the new staff plate and an offset of 2.99 feet were determined, the recorded stage data was shifted down 2.99 feet. Six check measurements plot -0.1 feet from the rating curve created with Equation 3. Equation 3 was replaced by a new rating curve, which incorporated the six check measurements and the new staff plate offset.

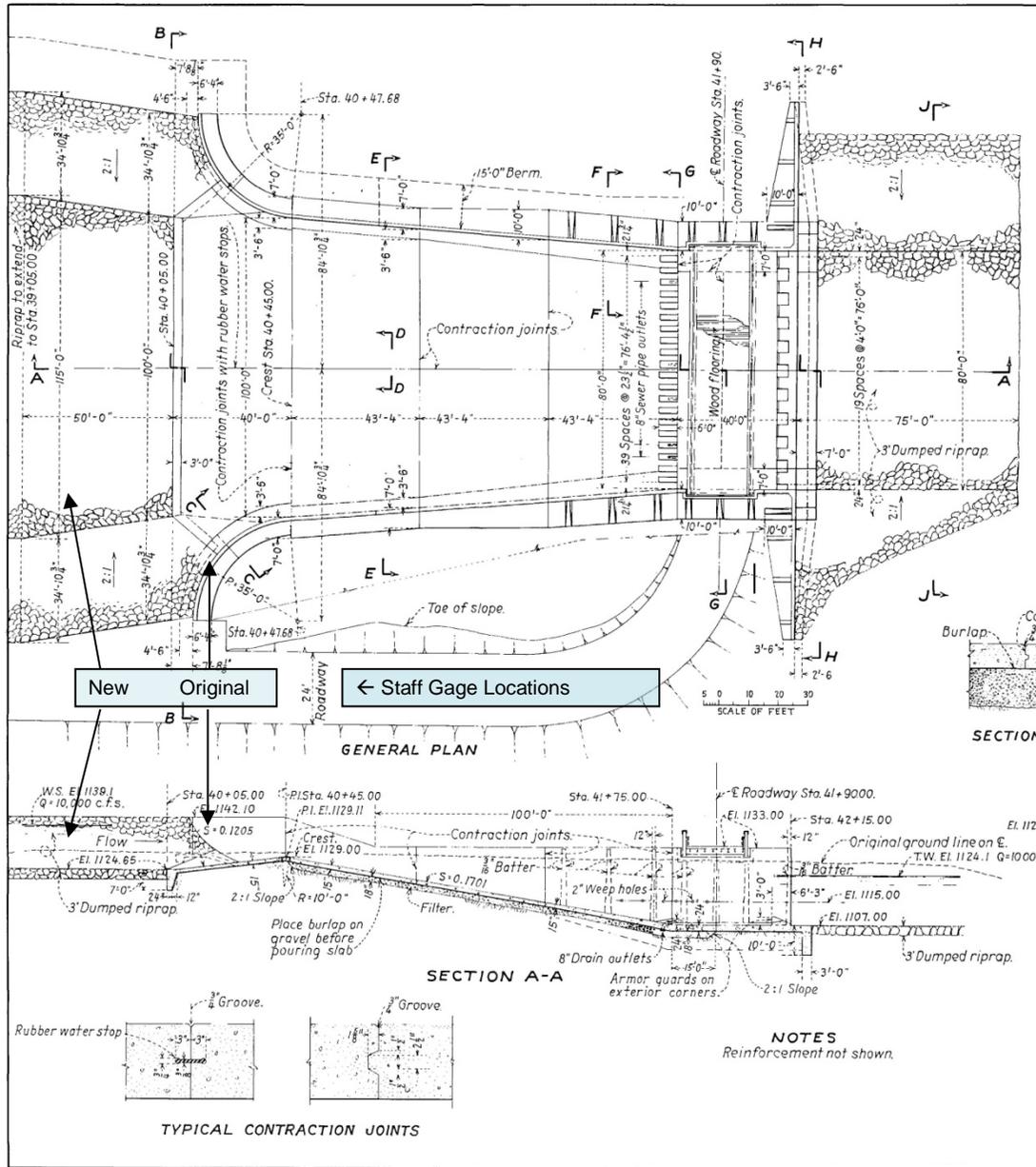


Figure 4. The figure shows the approximate location of staff gage for measuring height of water above the Hatchery Channel at Spillway. A plan view of the spillway is shown in the top part of the figure and the cross-section (A-A, identified in the plan view) is shown in the bottom of the figure. This is from the original Bureau of Reclamation drawings of the spillway.

Snow Lakes and Snow Creek

Snow Lake Outlet

Water in Upper Snow Lake is artificially released to Snow Creek through outlet works constructed by the Bureau of Reclamation in the 1940s. The Bureau of Reclamation built the outlet works by blasting a tunnel into granite underneath the lake, installed a 30" pipeline and fitted it with a 20" butterfly valve that releases water from Upper Snow Lake. Water from the lake flows down a talus slope into Nada Lake, enters Snow Creek and eventually flows into Icicle Creek. LNFH personnel release water from Upper Snow Lake to supplement Icicle Creek during the low flow period between mid-July and October 1st of each year. LNFH personnel open and adjust the valve manually. Flow through the 20" butterfly valve is calculated using the following equation:

$$\text{Equation 4.} \quad Q = \left(\frac{C_q}{0.0751} \right) * \sqrt{H}$$

Where: Q = Discharge from the outlet valve (cfs)

C_q = Coefficient based on the valve opening

H = Height of water recorded by pressure transducer gage in outlet tunnel (gage position (ft) + 11.3). 11.3 is the elevation difference between the pressure transducer and the 20" outlet valve.

The height of water above the 20" butterfly valve is measured using a 100 psi pressure transducer mounted on the 30" delivery pipeline. The pressure transducer output, in pounds per square inch (psi), is converted to feet by multiplying by 2.3703. A datalogger records pressure transducer heights at 4 hour intervals. The size of the butterfly valve opening is marked on its valve stem with 3 points; 0, 45, and 90 degrees. LNFH personnel record the pressure transducer, pressure gage and valve openings during visits to the outlet tunnel 3-6 times per year. These data are used to calculate mean daily water levels, releases, and storage volume at Upper Snow Lake for each day of the year.

The butterfly valve stem is insufficiently marked to set the valve to an exact opening except at the 3 marks previously listed. To determine valve opening at other angles LNFH personnel have gained experience in best approximating the valve stem opening that corresponds with the desired flow out of Snow Lakes. Estimated releases were checked by measuring flow through a modified Parshall flume at the outlet of Nada Lake.

Additionally, total estimated releases are checked against the observed change in Snow Lake volume, determined using a capacity curve developed by the Bureau of Reclamation in 1939 (Figure 5), at the end of the release season. The Service has used Equation 4 since water year 2004 and found that the results show that it is a good measure of releases from the lake.

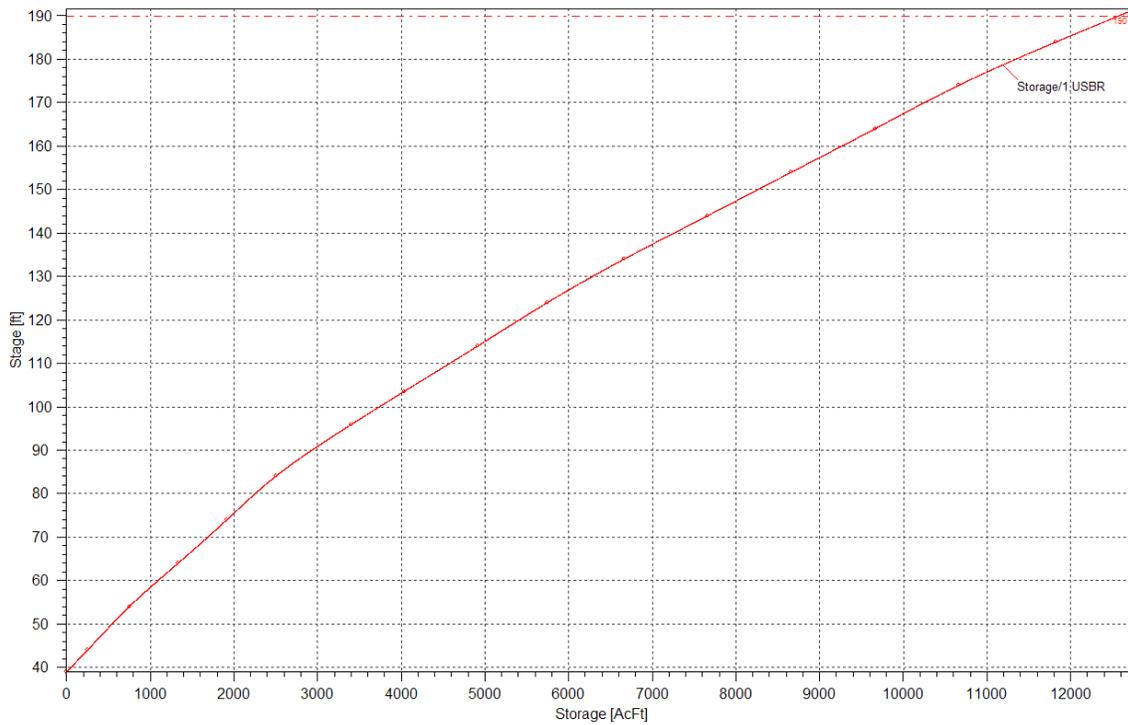


Figure 5. Volume of water stored in Upper Snow Lake vs. height of the lake’s water surface above the tunnel’s pressure gage.

Snow Creek Mouth Site

The Service has maintained a stream gaging station 600 feet upstream of the mouth of Snow Creek since 1997. The site measures releases and natural outflow from Nada Lake and Snow Lake as well as any additional flow from tributaries feeding Snow Creek upstream of the site. A combination broad-crested/v-notch cement weir spans the creek channel and provides control for measurement. The Service has developed a rating equation to calculate stream flow at the site. Flow measured at this site quantifies the amount of water entering Icicle Creek from Snow Creek and verifies flow released from Snow Lake. Wading measurements are made 1 foot upstream of the combination weir using a Price AA or SonTek Flowtracker current meter.

The site is equipped with a stilling well, a pulley/float shaft encoder, and datalogger for recording hourly water levels above the combination weir. The site was visited every 8-10 weeks during water year 2012 to make check discharge measurements and to download data.

Inflows and Outflows from the LNFH

LNFH Icicle Creek Diversion

The surface water intake facility for both LNFH and Cascade Orchard Irrigation Company (COIC) is located approximately 1 mile upstream of Structure 2 on Icicle Creek and contains several components. The intake system is gravity-fed and relies on a low rubble masonry diversion dam with a concrete spillway crest across Icicle Creek at RM 4.5. The dam raises water elevations several feet allowing a portion of the flow to be diverted through a grizzly rack (bars spaced at about 6 inches) and into a concrete water conveyance channel. In the late 1980's, the Service reconstructed the diversion dam with a pool and weir fish ladder. Water that enters the conveyance channel is transported a short distance to a small building which houses a second finer rack (1 ½ inch bar spacing), an overflow spill section, and a sediment sluicing section. From this point, most of the water is conveyed to the LNFH through a 33-inch diameter buried pipeline and a small portion spills back to the creek downstream of the building. A gate valve, which remains open, regulates flow into the buried pipe. Approximately 1,260 feet down gradient from the beginning of the pipe system is a gate valve that controls flow into the delivery system for COIC. COIC has a 1905 water right for 12.4 cubic feet per second (cfs) during the irrigation season (approximately May 1st through October 1st) and LNFH holds a 1942 water right to divert 42 cfs all year long.

A side-looking acoustic Doppler velocity meter (ADVM) was installed on the south side of the conveyance channel along the concrete wall to measure flow diverted from Icicle Creek. The flow measured by the ADVM includes the flows conveyed to the LNFH, the return flow from the overflow spill section in the house, the flows diverted to COIC, the return flow from the overflow spill section at the pipeline diversion for COIC, flows overbanking the diversion channel during high flows from Icicle Creek, and potential unknown leaks from the pipeline itself. The flows downstream of the ADVM and before the LNFH are not measured and therefore the LNFH intake is calculated based on the assumption of flow amounts to each of the diversions after the ADVM and before the LNFH. Estimated flows diverted after the ADVM and before the LNFH range between 0 and 15 cfs during the summer months and low Icicle Creek flows and between 15 and 60 cfs during high Icicle Creek flows.

The ADVM uses acoustic Doppler technology to measure water velocity which is multiplied by the area of the channel to calculate discharge. The channel profile or area is determined from each stage level and is checked regularly. The ADVM velocity data is checked using an Index Velocity method (Ruhl and Simpson, 2005) used by the USGS.

Production Wells 1-7

Groundwater provides a smaller component of Leavenworth NFH's water delivery system. The Leavenworth NFH operates seven wells, which produce the quality of water needed to sustain the current fish production program. The wells are located on the west bank of the hatchery channel and withdraw water from two aquifers, one deep and one shallow. Well 5 draws from the deeper aquifer, which is not influenced locally by surface water. Wells 1-4 and 7 withdraw water from the shallow aquifer. Well 6 draws water from both aquifers. Recharge of the shallow aquifer is affected by how much flow is present, and thus percolates into groundwater, in the historical and hatchery channels. The water levels in wells 1- 4 and 7 rise when water is in the hatchery channel and fall when water is not present in the hatchery channel. Well water is used to supplement surface water to meet fish production temperature tolerances. Production wells are outfitted with inline flow meters, pressure transducers, and thermistors to measure well discharge, well level, and water temperature, respectively. Instrumentation was not recording correctly for Production Well # 3 between 02/19/2012 and 03/20/2012, for Production Well #4 between 03/22/2012 and 09/30/2012, and for Production Well #7 between 03/27/2012 and 09/30/2012.

LNFH Discharge at Fish Ladder (Outfall 1)

All of the surface water and groundwater used at the LNFH, minus any leakage or evaporation, is returned to Icicle Creek immediately downstream of the LNFH. This water is discharged into Icicle Creek at two locations, immediately downstream of the hatchery channel spillway at the base of a fish ladder (RM 2.8) or through the pollution abatement pond (RM 2.7). The return flow, which varies seasonally from 42-60 cfs, is combined with the outfall from a 30 inch pipe before flowing through a 3-foot concrete Parshall Flume. Greater than 98 percent of the water is returned to Icicle Creek through the Parshall Flume except that when the rearing units are cleaned, a larger portion is returned through the Pollution Abatement Pond. Recording equipment includes a Siemens ultrasonic water level sensor and is housed in a wooden shelter mounted on the stilling well connected to the flume. The

equipment was in operation throughout water year 2012. The water levels from the Siemens sensor are used to calculate discharge using a theoretical equation. Data is stored immediately at the LNFH computer system.

Potential problems with this site are two-fold. One problem is the flume is too closely connected to the Icicle Creek such that when Icicle Creek flow increases, the flume is submerged and flow is overestimated. This problem could be alleviated by utilizing the second stilling well that currently exists at the flume to measure downstream water levels during submergence. The second stilling well is currently disconnected from the flume due to blockage in the connection between the stilling well and the flume. Efforts were made to remove the blockage although a connection was not reestablished. Additionally, only one parameter can be stored in the LNFH computer system and currently it is the calculated discharge value. The water levels recorded in the stilling well need to be recorded as well in order to check the measurements of the ultrasonic water level sensor.

LNFH Discharge at Abatement Pond (Outfall 2)

The second LNFH water discharge into Icicle Creek is through one or both pollution abatement ponds (RM 2.7). Continual overflow from routine operations and daily cleaning effluent is usually routed through only one pollution abatement pond. Starting the beginning of February 2012 a faulty gate in the nursery effluent pipe required an emergency release into both pollution abatement ponds. The pollution abatement pond that was not in use until this time was not outfitted with measurement equipment until February 7, 2012 when water level recording instrumentation was installed. During normal flow operations at the hatchery, at least one section of the rearing units is cleaned nearly every day releasing approximately 4 cfs to Icicle Creek during the 2-hour cleaning period. The sand settling basin has an overflow bypass pipe which also empties into the Pollution Abatement Pond. The Pollution Abatement Pond discharges approximately 1 cfs (daily average) or less than two percent of the total effluent discharge for the LNFH. The outflow of Pollution Abatement Pond 1 (PAP1) was measured with a 90 degree V-notch weir, a shaft encoder, and datalogger all year. The outflow of Pollution Abatement Pond 2 (PAP2) was measured using a rectangular weir, a shaft encoder, and a datalogger starting February 9, 2012 and a 90 degree V-notch weir starting May 7, 2012. Discharge through PAP1 occurred all year and discharge through PAP2 occurred between the following dates; February 9 and March 21, April 17 and June 25, between September 12 and September 14. Flows from both PAPs were combined for a final value of flow for the PAP discharge to Icicle Creek.

Temperature

Temperature was measured at all flow contributions and releases to and from the LNFH. Surface water temperatures around the LNFH are monitored with HOBO temperature loggers at three locations: LNFH Icicle Creek Diversion, LNFH Discharge at Fish Ladder (Outfall 1), and LNFH at Abatement Pond (Outfall 2). For quality assurance purposes, the HOBO temperature loggers were tested in two temperature baths representing the extremes of their monitoring conditions. The baths were made in coolers and had either an aquarium powerhead or air pump/stone added to mix the water and ensure a uniform temperature. One bath was maintained at room temperature (approximately 21 degrees Celsius, 69.8 degrees Fahrenheit) and the second bath was maintained close to freezing (0 degrees Celsius, 32 degrees Fahrenheit), using cold tap water and 10 ice cube trays of ice. A lid was placed over this second cooler, except for a 1-inch opening to allow access for the thermometers. Temperatures were allowed to stabilize in both baths for ½ to 1 hour and the loggers were acclimated to the baths for at least 1/2 hour before temperature testing began. Water temperatures in the baths were recorded at 5-minute intervals by a National Institutes of Standard Technology (NIST) certified thermometer, a YSI temperature logger and the HOBO loggers.

After the calibration tests were concluded, the data was downloaded to HOBO software and exported to Excel for comparison with the NIST reference thermometer. If the mean absolute value of the difference was greater than 0.2 degrees Celsius (+/- 0.36 degrees Fahrenheit) the thermometers were tested again. If the mean difference was still more than +/- 0.2 degrees Celsius (+/- 0.36 degrees Fahrenheit) they were not used in the sampling.

In 2012, temperature thermistors used in the production wells were not checked due to the inability to remove and check the thermistors with a NIST thermometer in the same bath water. In the future, temperature checks will be attempted by quickly measuring a well water sample with the NIST thermometer and comparing that to the logger reading. Due to the constraints of measurement the temperatures checks will not provide assurance of accuracy within the specifications of the thermistor.

Data Handling Quality Assurance

The Service made check discharge measurements by either using the wading measurement technique with a Price AA, or SonTek FlowTracker, or by using boat methods with an ADCP. Wading measurements followed the United States Geological Survey' (USGS) midsection method (Rantz et al. 1982). Records for these monitoring sites were worked following the standard procedures established by the USGS (Rantz et al. 1982). Raw data and worked records were stored in the WISKI-7 database at the USFWS Water Resources Branch Office in Portland, OR.

RESULTS

Historical Channel and Hatchery Channel

Historical Channel at Structure 2

Flows from Icicle Creek at Structure 2 are shown in figure 6. Flows calculated over 1680 cfs were considered estimated due to the lack of available check flow measurements to corroborate high flows. These flows occurred intermittently between April 24, 2012 and June 23, 2012. Data is also estimated during freezing temperatures when ice was present in the stilling well and when the datalogger malfunctioned. Freezing temperatures and ice formation occurred between December 1, 2011 and January 22, 2012. Bubbler malfunction occurred between November 15, 2011 and March 7, 2012, when the bubbler was replaced. Throughout this time period and during many days the bubbler stage values spiked for a few hours or more at an interval of once a week, once a day, and up to 6 times a day. The spikes were deleted and the values in between were interpolated based on the data points conjoining the deleted time frame. The flows measured at the Icicle Creek above Snow Creek (USGS, 2012) were compared to the Icicle Creek near Leavenworth (Ecology, 2012) (figure 7). The Icicle Creek above Snow Creek site is located just upstream of the Snow Creek input to Icicle Creek and the Icicle Creek near Leavenworth site is located one-half mile downstream of the last of LNFH operations. The shape of the hydrograph of Hatchery Channel at Structure 2 site follows the shape of the hydrographs from the Icicle Creek above Snow Creek and Icicle Creek near Leavenworth stream gaging sites.

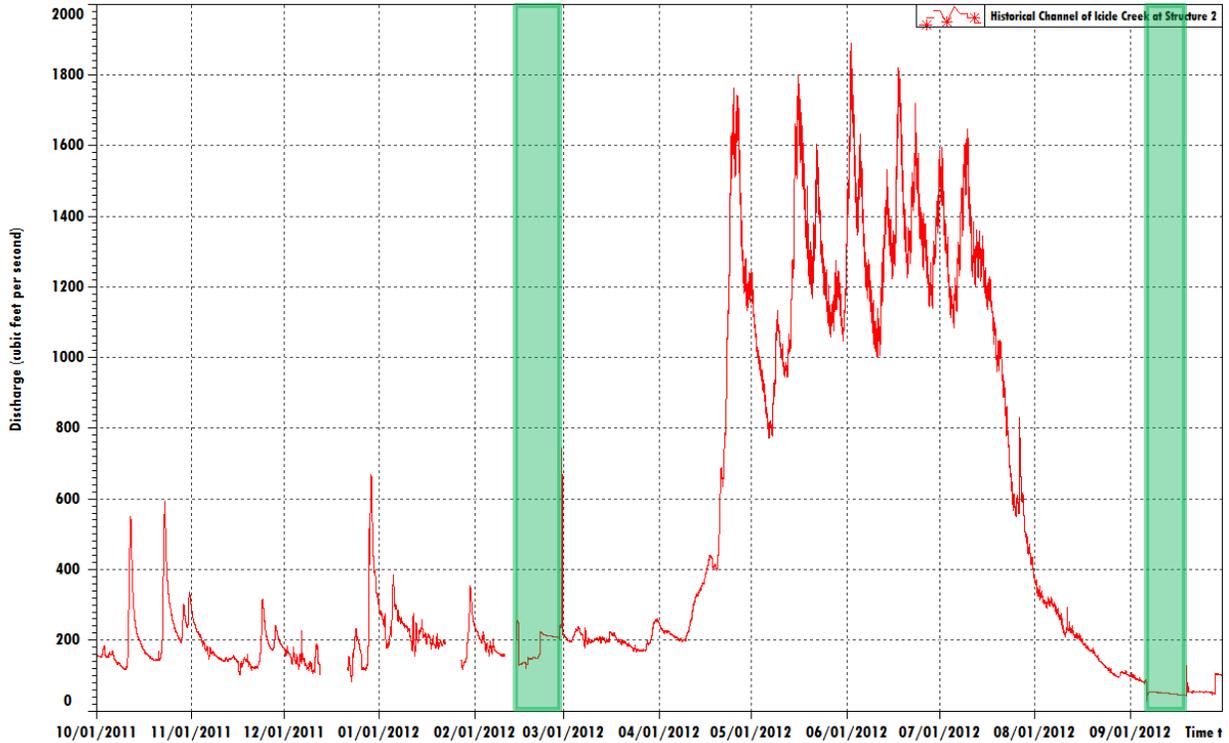


Figure 6. Hydrograph of discharge (Q) in cfs through Historical Channel of Icicle Creek at Structure 2 (322525) for Water Year 2012. Green bars indicate timing of when the radial gate was lowered to divert water into the Hatchery Channel.

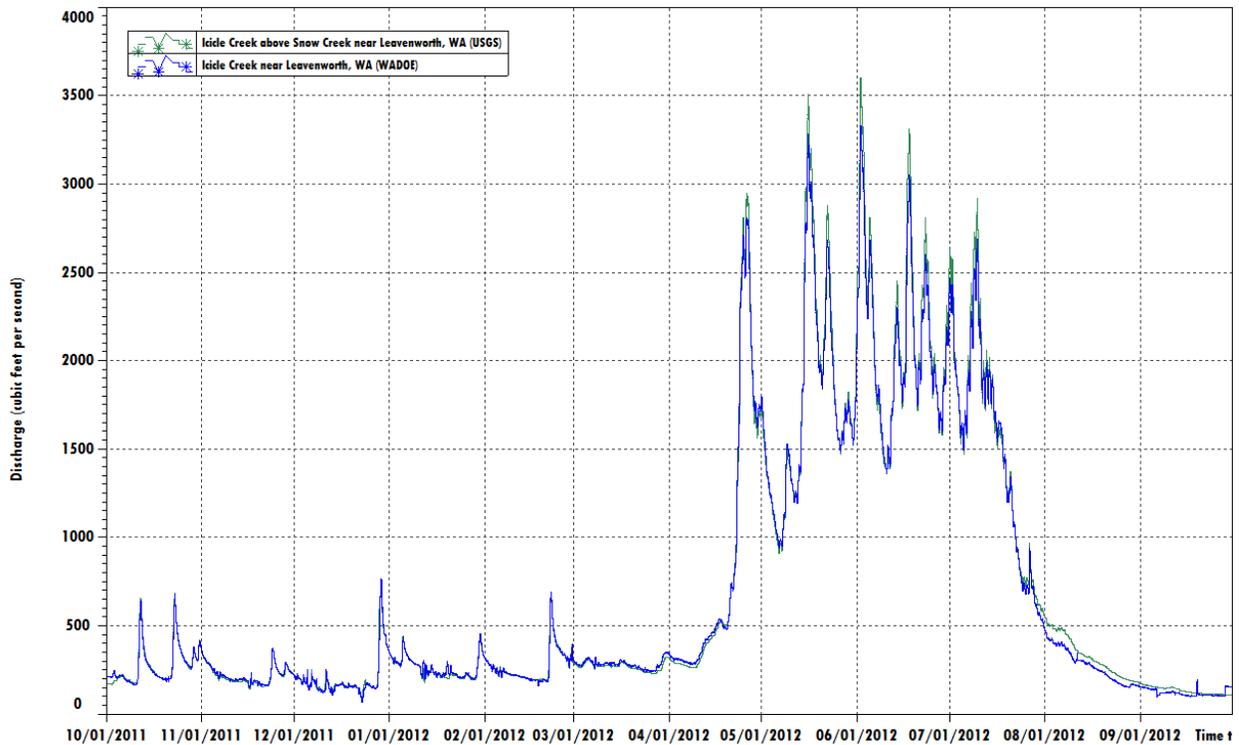


Figure 7. Hydrograph of discharge (cfs) measured at the USGS site – Icicle Creek above Snow Creek (in green) and the Washington Department of Ecology site – Icicle Creek near Leavenworth (in blue) for water year 2012.

Hatchery Channel at Spillway

Flows at the Hatchery Channel at Spillway site are shown in figure 8. Continuous recorded data began on May 10, 2011. Flows over the spillway occurred part of the time when the radial gates on Structure 2 were lowered. These times include the dates between February 22, 2012 and February 29, 2012, between September 7, 2012 and September 7, 2012, and then again during and during high spring flow runoff in Icicle Creek starting on April 23, 2012 that continued through July 22, 2012 when Icicle Creek flows declined.

Head at the Historical Channel at Structure 2 site dictates the water levels and flow at the Hatchery Channel at Spillway site. An x-y coordinate plot shows the correlation between stage (figure 9) and discharge (figure 10) between the Historical Channel at Structure 2 site and the Hatchery Channel at Spillway site the stage. In figure 9, water levels of 2.47 feet (348 cfs) measured with the wire-weight gage at the Historical Channel at Structure 2 site occurs when the lowest water levels are present at the Hatchery Channel at Spillway site. When water level reaches 4.41 feet and flows of 830 cfs occur at the structure 2 site, the water level reaches 2.99 feet and flow begins to spill over at the Hatchery Channel at Spillway site. The comparison of discharge data from the Spillway site that occurred when the radial gate was lowered at the Structure 2 site does not line up on the regression and these values are noted on the graph with a green circle.

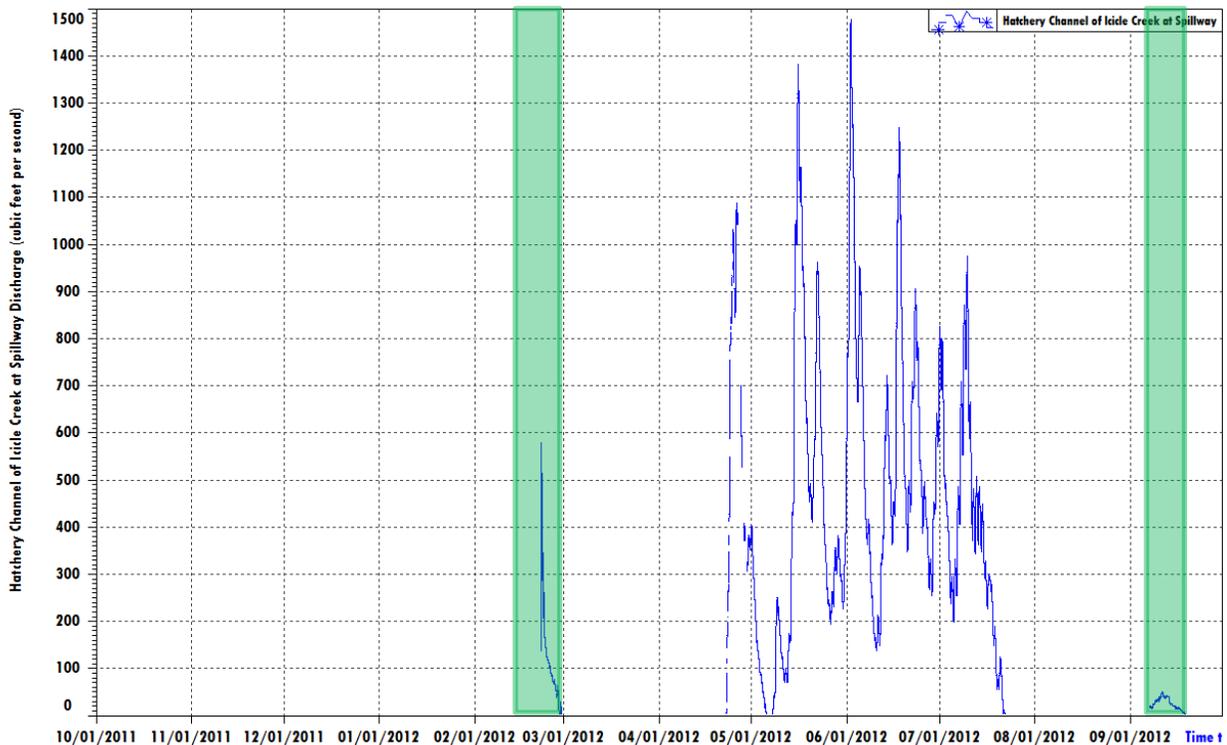


Figure 8. Hydrograph of discharge through the Hatchery Channel at Spillway site (322527) for Water Year 2012. Green bars indicate timing of when the radial gate was lowered to divert water into the Hatchery Channel.

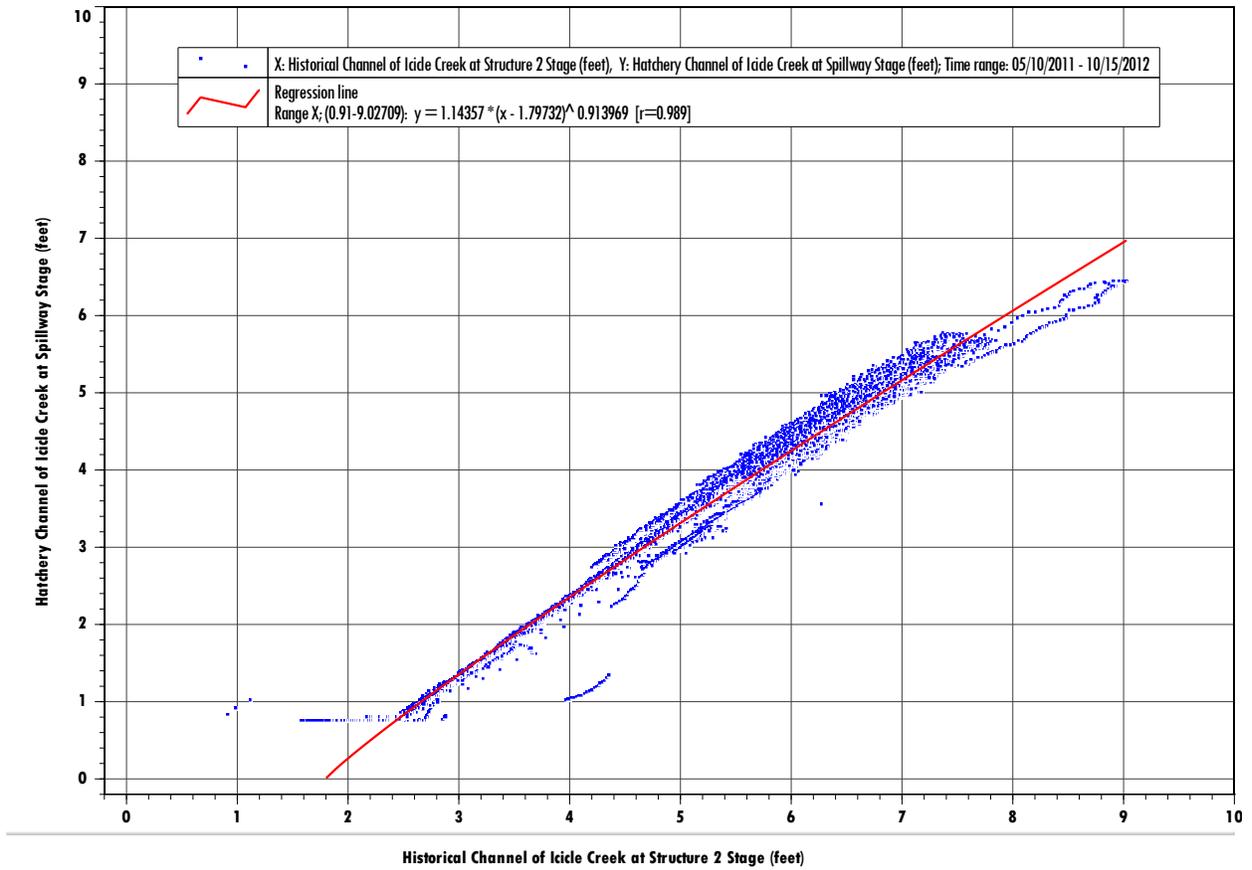


Figure 9. An x-y and regression plot of stage values (feet) for Historical Channel at Structure 2 and Hatchery Channel at Spillway in blue dots and regression line in red.

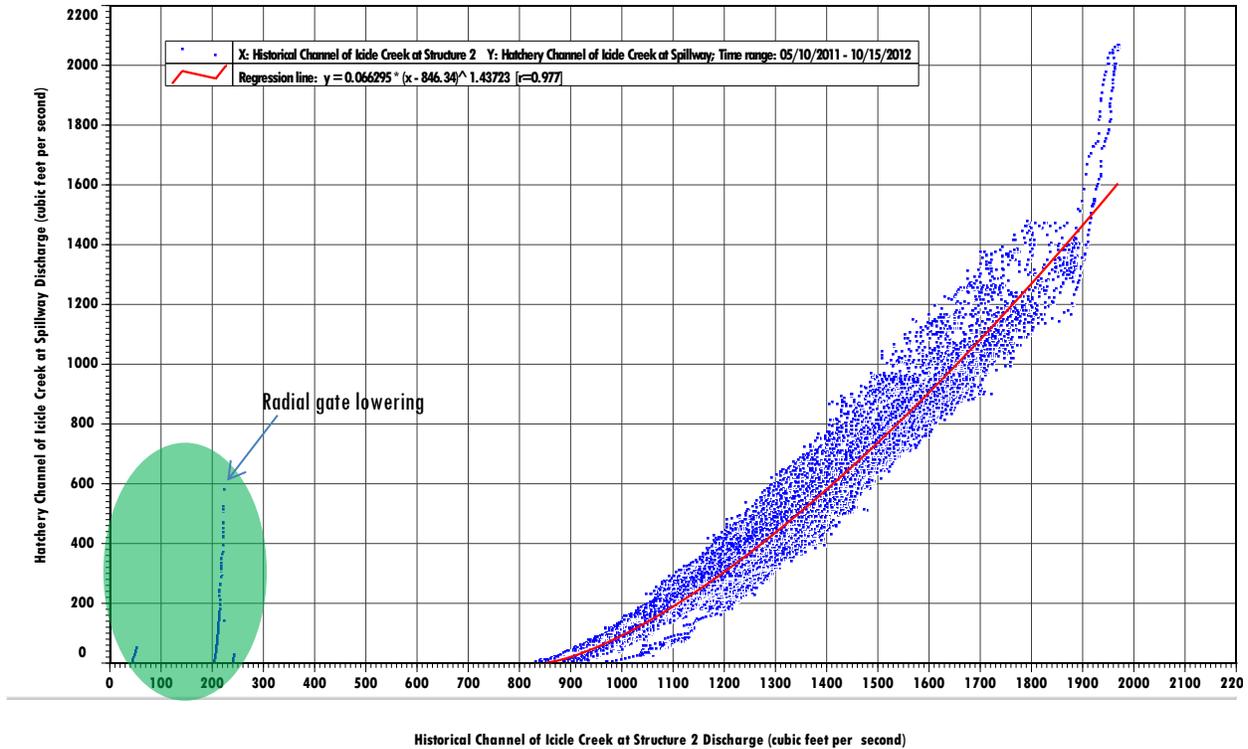


Figure 10. An x-y and regression plot of discharge values (cfs) for Historical Channel at Structure 2 and Hatchery Channel at Spillway site in blue dots and regression line in red. Values in in plot used for regression do not include data collected when the radial gate was lowered.

Snow Lakes and Snow Creek

Snow Lake Outlet

Discharge (cfs) released from the outlet pipe and total storage (ac-feet) from the Snow Lakes Outlet site is shown in figures 11 and 12. The outlet valve was opened 25 degrees on July 31, 2012 (Table 5). Two subsequent valve changes occurred before the outlet valve was closed for the winter on October 2, 2012. Total storage for Snow Lakes increased from 8,590 ac-feet on October 3, 2011 to 12,500 ac-feet on June 1, 2012. Storage dropped to 5,800 ac-feet by the time the valve was closed on October 2, 2012. The difference of 6,700 ac-feet between these two points represents the total volume released for the season.

Table 5. Snow Lakes Outlet valve adjustments.

Date	Valve Adjustment
07/31/2012	25-degrees
08/10/2012	45-degrees
08/28/2012	53-degrees
10/02/2012	0-degrees

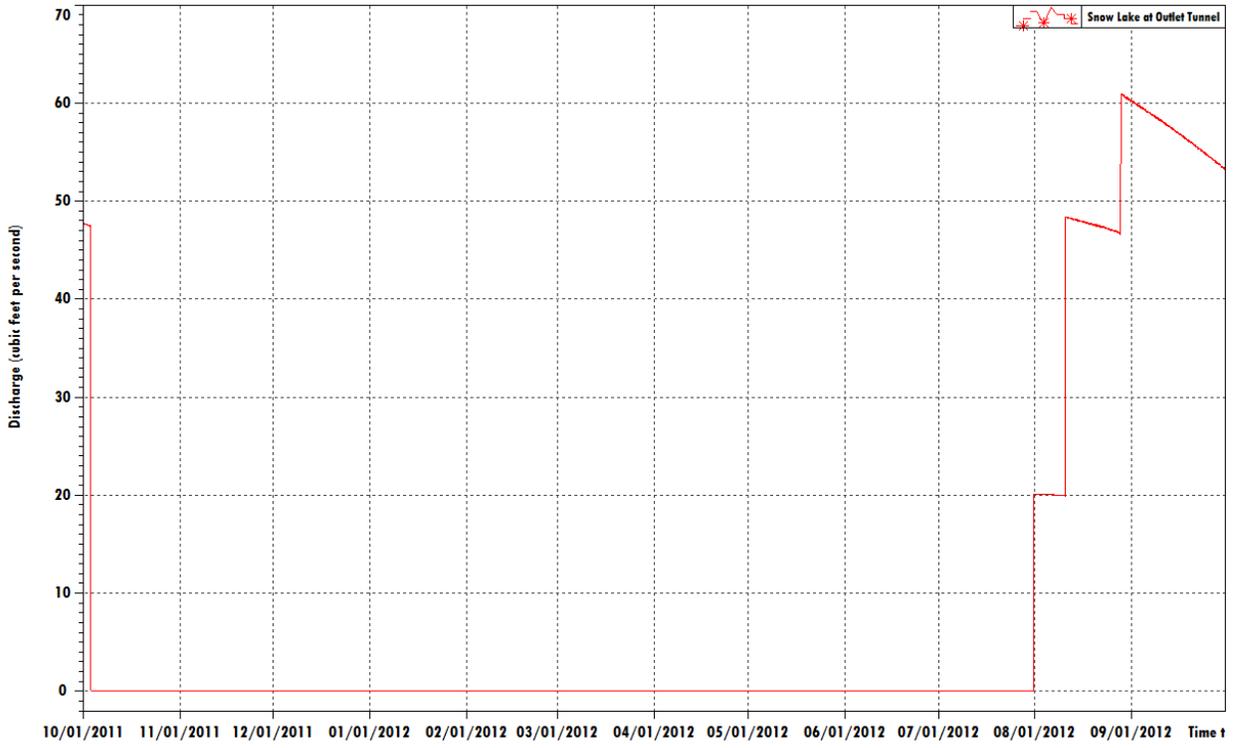


Figure 11. Hydrograph of discharge through the valve at the Snow Lakes Outlet (322506) for Water Year 2012.

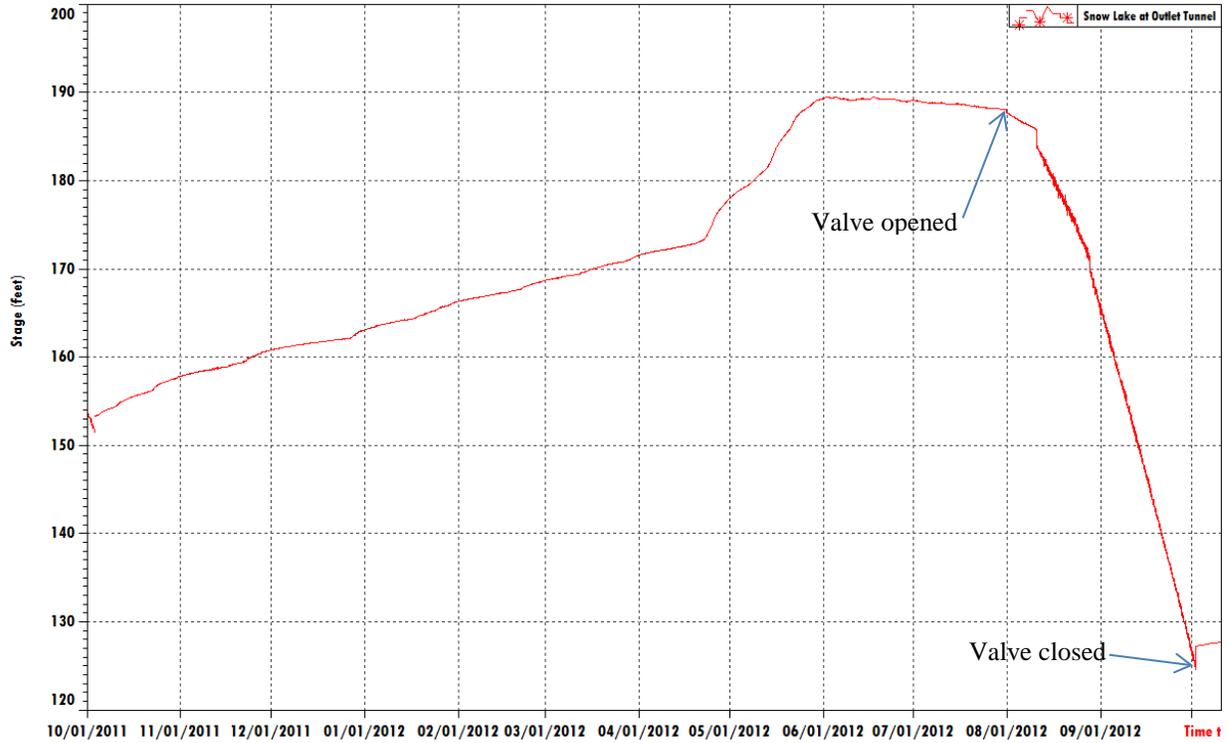


Figure 12. Hydrograph of volume storage in the Snow Lakes Outlet site (322506) for Water Year 2012.

Snow Creek Mouth

A discharge hydrograph for the Snow Creek Mouth site is shown in figure 13. Discharge was not calculated between December 5, 2011 and February 22, 2012 due to ice conditions. The timing of peakflow in Snow Creek is similar to that in Icicle Creek. Discharge increases at Snow Creek Mouth after July 28 were related to releases from Snow Lake. The Snow Creek hydrograph shows a late summer increase in response to releases from Snow Lake rather than a typical late summer streamflow decrease (figure 14).

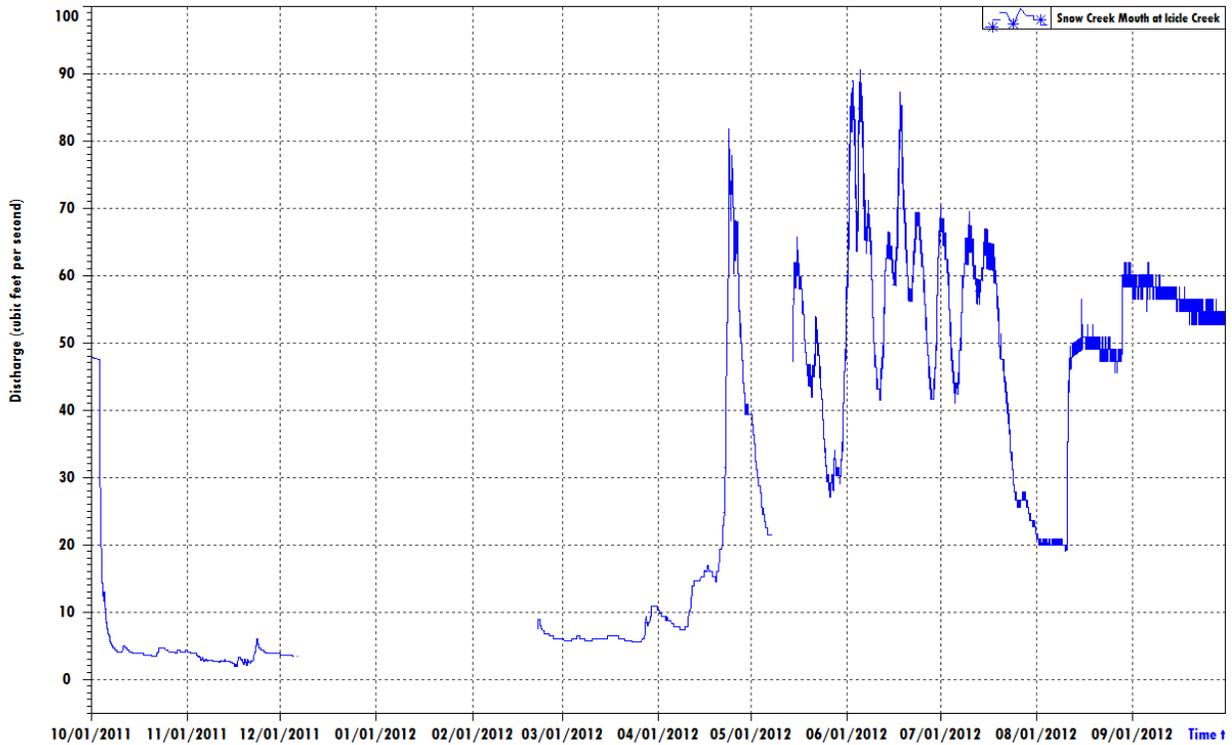


Figure 13. Hydrograph of discharge at the Snow Creek Mouth site (322503) for Water Year 2012.

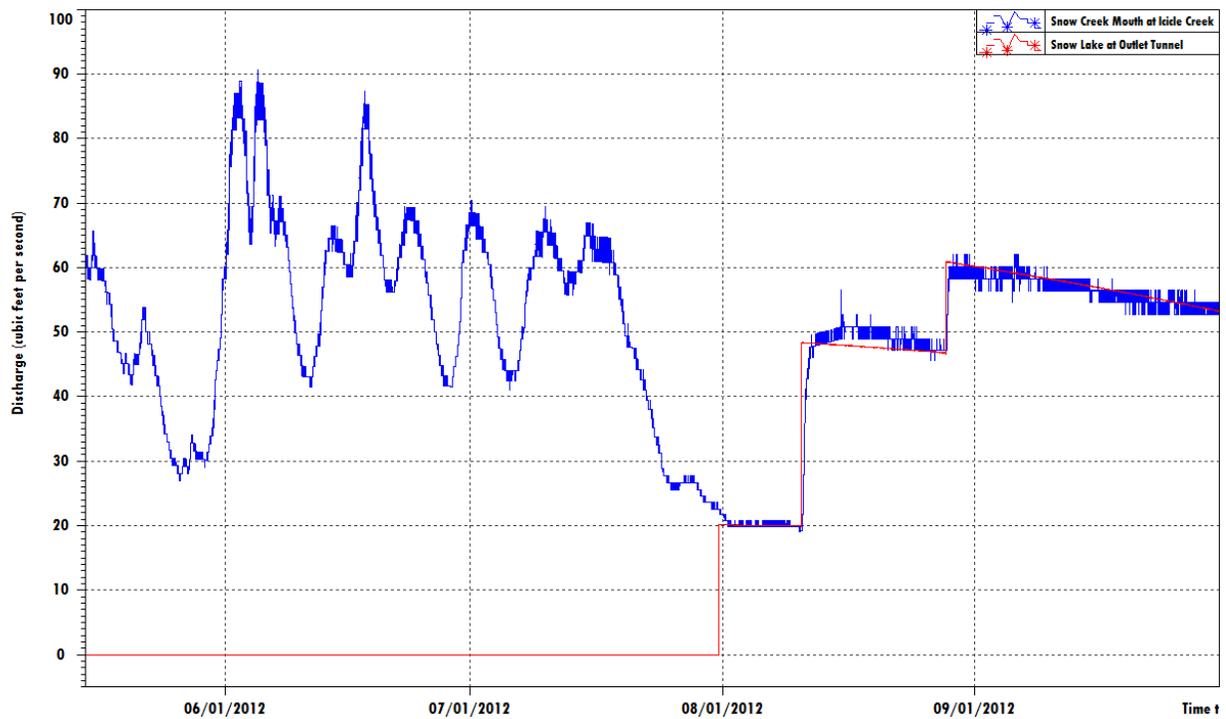


Figure 14. Hydrograph of continuous discharge (cfs) in the Snow Lakes Outlet site (322506) shown in the red line and discharge (cfs) in the Snow Creek Mouth site (322503) shown in blue line between 05/20/2012 and 10/01/2012.

Inflows and Outflows from the LNFH

LNFH Icicle Creek Diversion

A discharge hydrograph of the LNFH Icicle Creek Diversion site is shown in figure 15. Acquiring quality data was problematic due to high flows and rapidly changing sediment height and area profiles in the diversion channel. Starting April 22 and continuing through July, flows increased in the Diversion Channel as flows increased in Icicle Creek. Not all of the flow diverted into the intake diversion canal reaches LNFH or COIC, some water returns to Icicle Creek. At high flows in Icicle Creek increased flows in the diversion intake canal are released back to Icicle Creek either through the overflow spill section in the small building downstream of the diversion intake canal or over the banks of the diversion canal downstream of the point of measurement. The ADVN acoustic beams were likely obstructed at times by sediment filling into the canal between June 2 and July 11. When the Argonaut hydroacoustic beams are obstructed the velocities tend to be biased low which will result in underestimated flows. Higher flows from spring run-off in Icicle Creek transport greater amounts of sediment load and as the flows decline the sediment will slowly drop out of the water column and fill in the Intake Canal. Subsequently, during spring run-off the high and variable flows causes change in the profile geometry that is not quantified in the calculation of discharge. As a result, much of discharge between May 1 and July 16, 2012 is considered suspect. Discharge calculated between October 1, 2011 and May 1, 2012 and between July 16 and October 1, 2012 is considered estimated.

Before this site was created the changes in area profile geometry at the ADVN measurement point was not well understood, and for the second year in a row, the channel geometry was altered with such frequency and magnitude during the spring run-off period that it is difficult to measure flow into the diversion intake canal accurately. In addition, the workload was too great to dedicate enough time to capture changes in the area profile geometry that occur after high flows in Icicle Creek, site visits were not frequent enough to capture these changes.

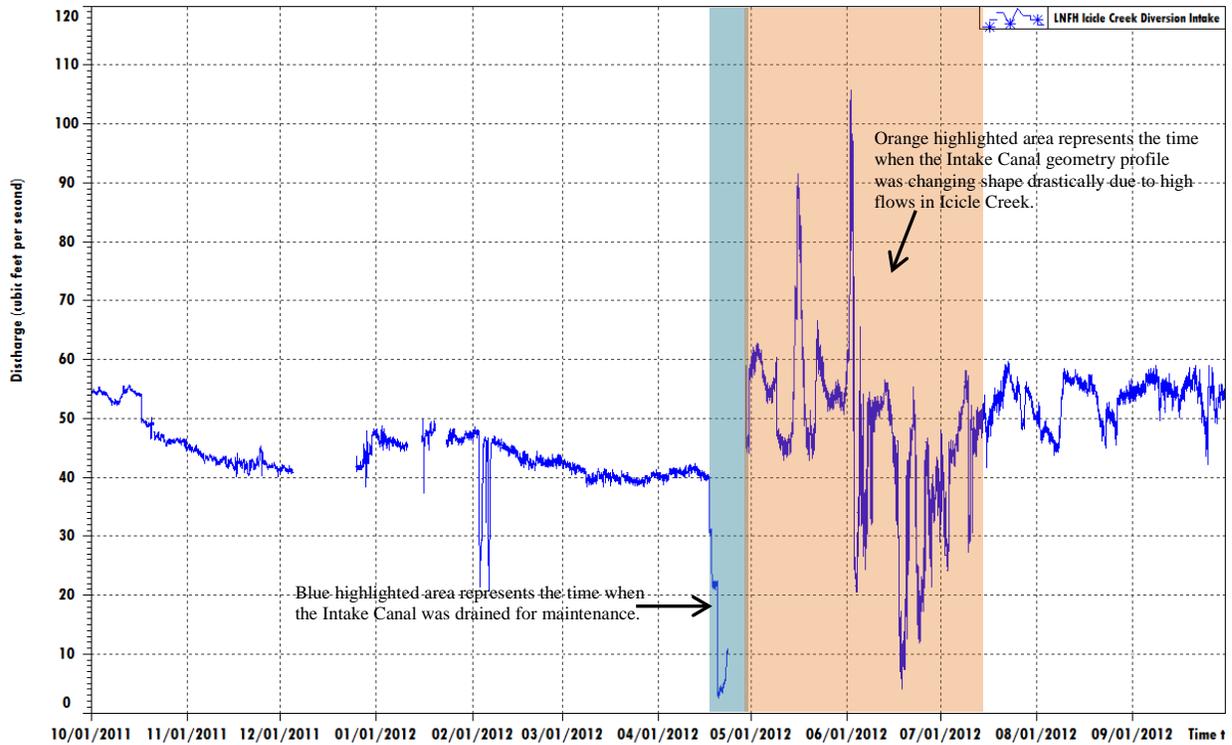


Figure 15. A hydrograph of flows through the LNFH Icicle Creek Diversion for Water Year 2012. The green line denotes the amount of flow for LNFH water rights and the orange line denotes the amount of flow for COIC water rights and addition to LNFH water rights.

Production Wells 1-7

Production well discharge is shown in figure 16 and 17. The sum of the total hourly well discharge is included in the hydrograph, with the scale on the furthest left y-axis. Data from production wells 4 and 7 are missing between April 2012 and October 2012 due to recording equipment failure.

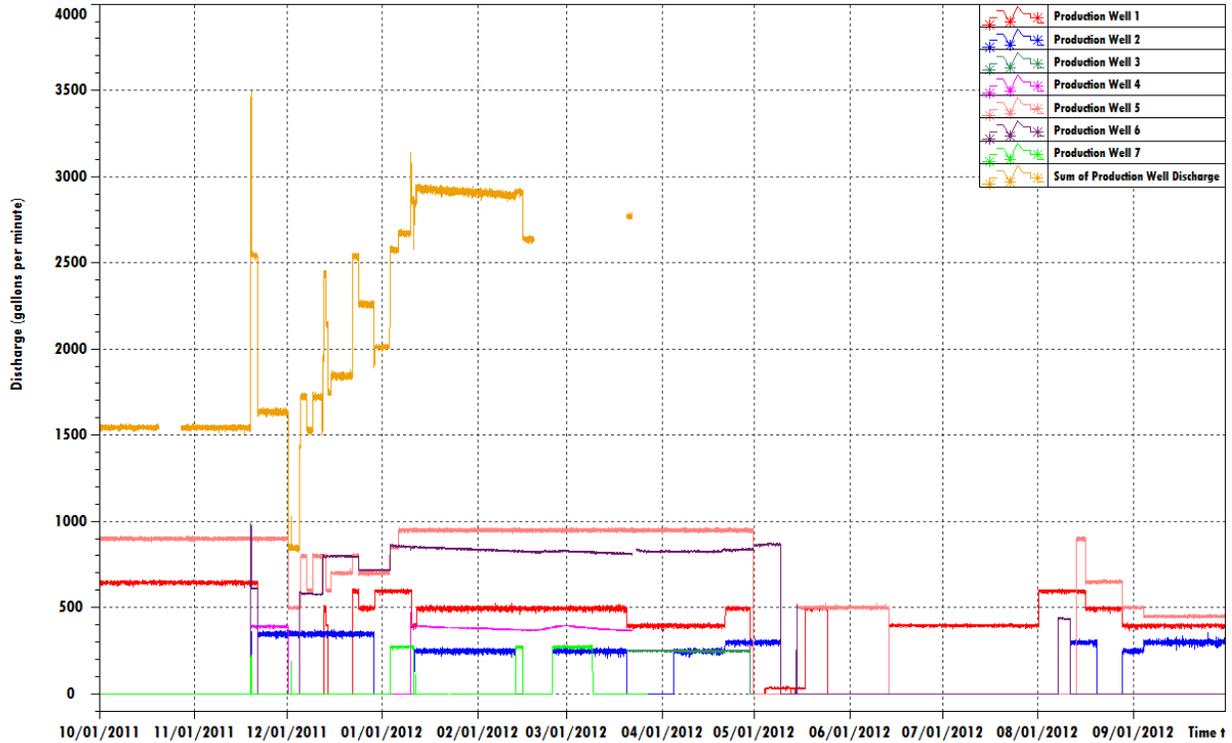


Figure 16. Hydrographs of well discharge (gpm) of Production Well: PW-1 (red), PW-2 (blue), PW-3 (green), PW-4 (pink), PW-5 (peach), PW-6 (purple), PW-7 (light green), and the sum of all hourly Production Well Discharge (gold) for Water Year 2012.

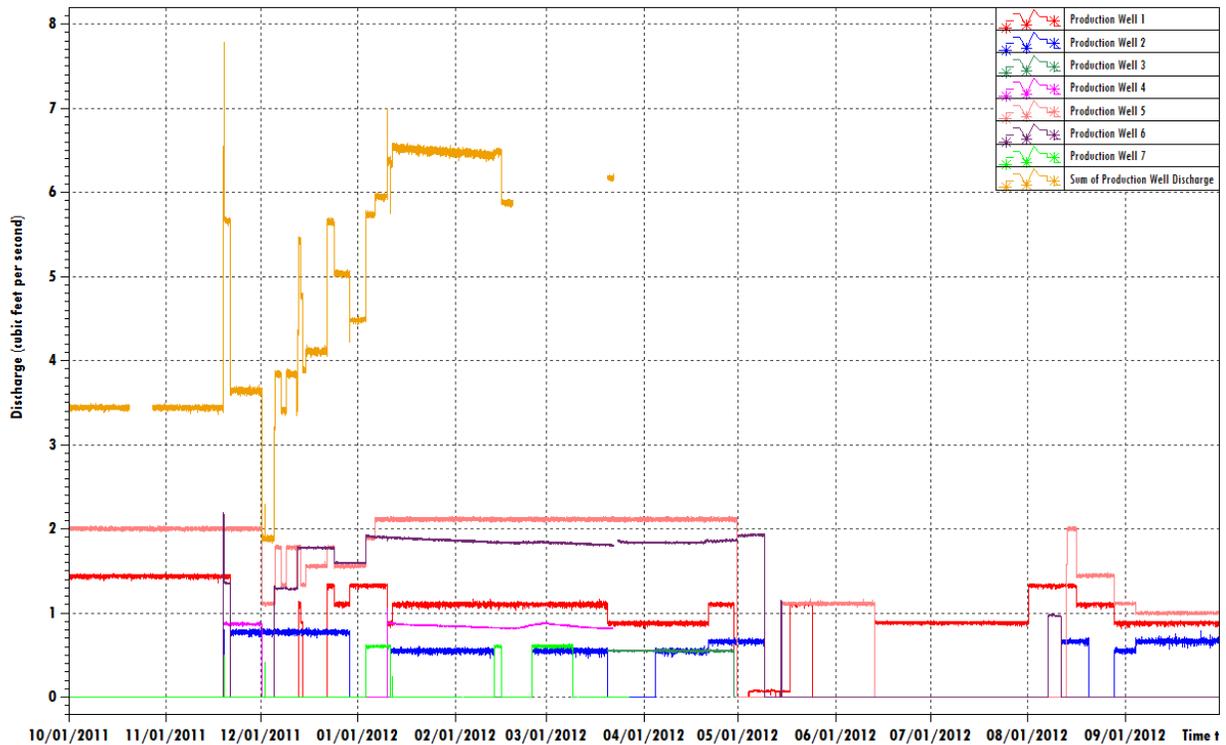


Figure 17. Hydrographs of well discharge (cfs) of Production Well: PW-1 (red), PW-2 (blue), PW-3 (green), PW-4 (pink), PW-5 (peach), PW-6 (purple), PW-7 (light green), and the sum of all hourly Production Well Discharge (gold) for Water Year 2012.

LNFH Discharge at Fish Ladder (Outfall 1)

Discharge calculated out of the fish ladder (Outfall 1) is consistent throughout the year, ranging between 35 and 50 cfs (figure 18). Flows above 55 cfs are likely too high to be representative of actual releases from the hatchery and are instead caused by submergence of the flume when flows in Icicle Creek exceed 1400cfs. Submergence occurred between May 14 and July 18, 2012.

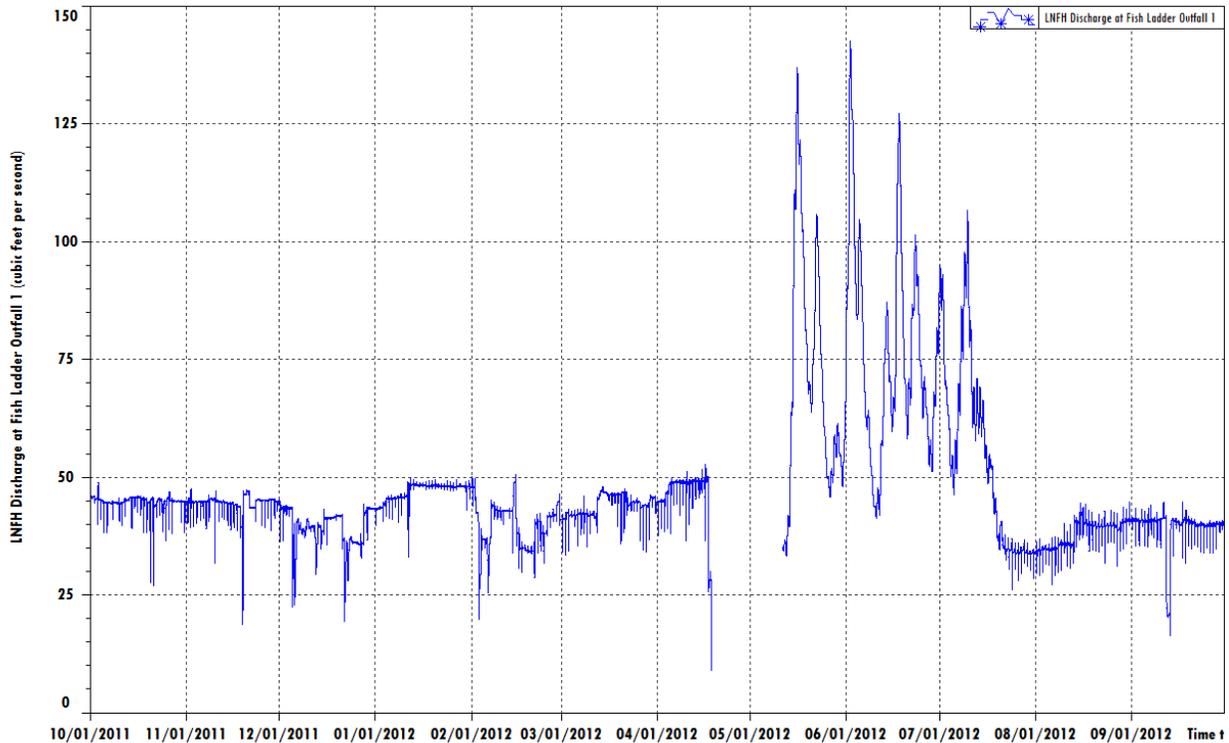


Figure 18. Hydrograph of discharge at the LNFH Discharge at Fish Ladder (Outfall 1) site (322501) for Water Year 2012.

LNFH Discharge at Abatement Pond (Outfall 2)

Discharge releases from the LNFH Pollution Abatement Ponds to Icicle Creek is a combination of discharge from two separate pollution abatement ponds when both ponds are being used. Flows range between 0 and 6 cfs (figure 19). Flows calculated above 6 cfs are considered estimated because they exceed the height of the v-notch weir (1.5 feet).

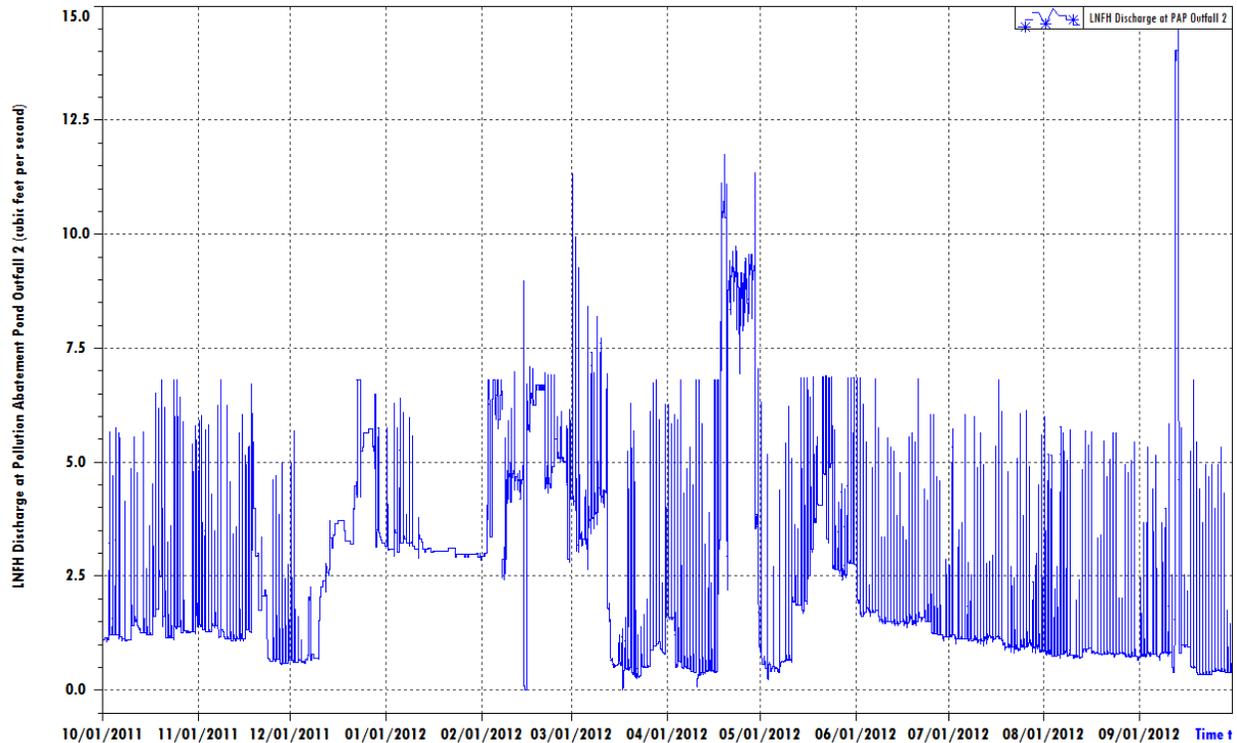


Figure 19. Hydrograph of discharge at the LNFH Discharge at Abatement Pond (Outfall 2) site (322502) for Water Year 2012.

Discharge and Flow-Average Temperature Comparison

A comparison of hourly inflows and outflows into the LNFH are shown in figure 20. Inflows into the LNFH include discharge from the LNFH Icicle Creek Diversion and the 7 Production Wells. Outflows of the LNFH include the LNFH Discharge at Fish Ladder (Outfall 1) and the LNFH Discharge at Abatement Pond (Outfall 2). Ideally, the Inflows minus Outflows hydrograph would result in a difference of 0 cfs. The difference shown on the graph is greater than zero most of the time and is attributable to diversions to COIC from May to October and the other diversions of unknown quantity downstream of LNFH Icicle Creek Diversion measurement and the LNFH. The Inflows (except Production Well 4 and 7) minus Outflows hydrograph does not include Production Wells 4 and 7 and is provided to view the inflow/outflow comparison for a longer period of time. The difference between the hydrograph with and without Production Well 4 and 7 data shows that the hydrograph without tends to be slightly lower, therefore the remainder of the year the hydrograph without 4 and 7 well data should be estimated slightly higher than what is shown. In November 2011 inflow minus outflow track very close to 0 cfs and are representative of actual flows into and out of the LNFH. Before November 2011 and after July 2012 the inflows at the LNFH Icicle

Creek Diversion are much higher than outflows at the LNFH Discharge at Fish Ladder. The discrepancy is due to withdraws for COIC and to an increase in diversion through the overflow spill section downstream of the diversion canal ADVM. As expected, there are large discrepancies between May 1, 2012 and July 15, 2012 when both the LNFH Icicle Diversion Intake and the LNFH Discharge at Fish Ladder sites were subject to inaccurate calculations of discharge due to high Icicle Creek flows.

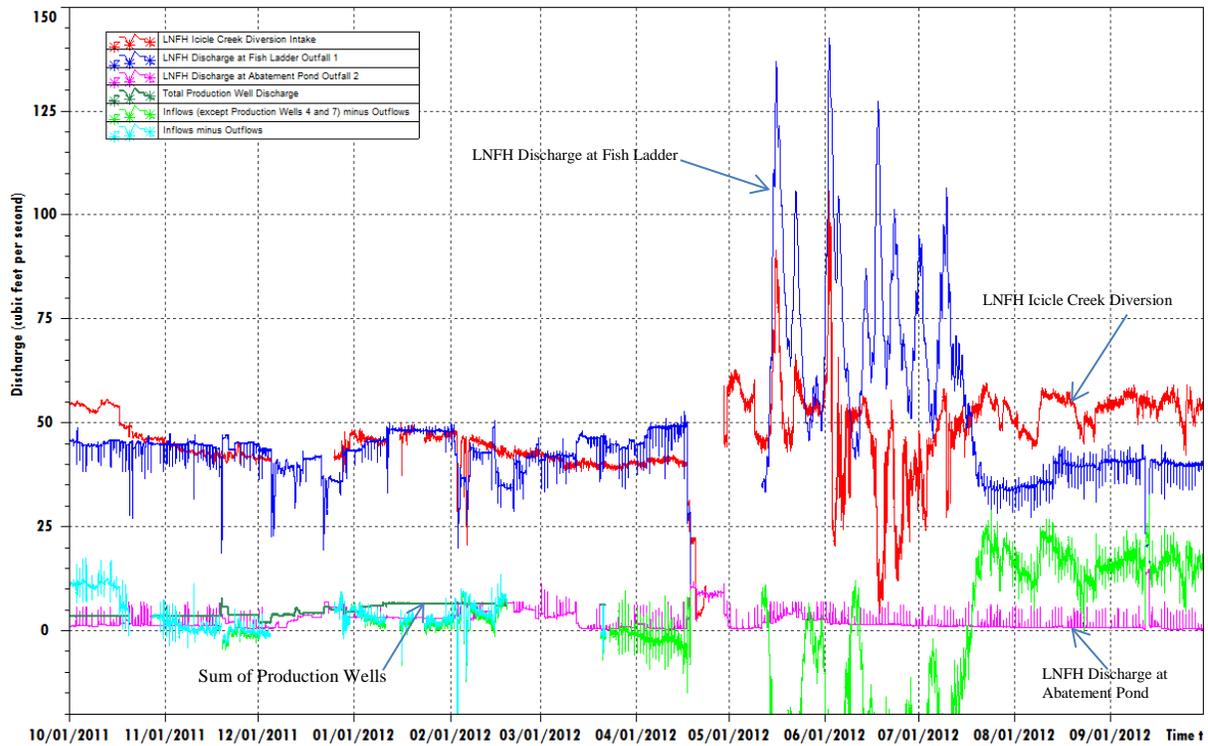


Figure 20. Discharge hydrographs (cfs) for hourly interval for the LNFH Diverstion Intake (red line), LNFH Discharge at Fish Ladder (Outfall 1) (blue line), LNFH Discharge at Abatement Pond (Outfall 2) (magenta line), Total Production Well Discharge (dark green line), Inflows minus Outflows (cyan line), and Inflows (except Production Wells 4 and 7) minus Outflows (light green).

Inflow and outflow temperatures are shown in figure 21. Water temperatures measured in the production wells range between 40 and 60 degrees Fahrenheit and were higher than temperatures measured at the surface water inflow and outflow sites during winter months. It would be expected that water temperatures measured at the LNFH Discharge at Abatement Pond were higher and more variable than temperatures measured at the LNFH Icicle Creek Diversion and LNFH Discharge at Fish Ladder during the summer months, due to the inherent design of the pollution abatement pond which exposes LNFH effluent to air temperatures and solar radiation over a large surface

area. Yet, in August during the highest temperatures, discharge from the LNFH Discharge at Abatement Pond is very small relative to the flows in Icicle Creek and should not be significant in affecting Icicle Creek temperatures.

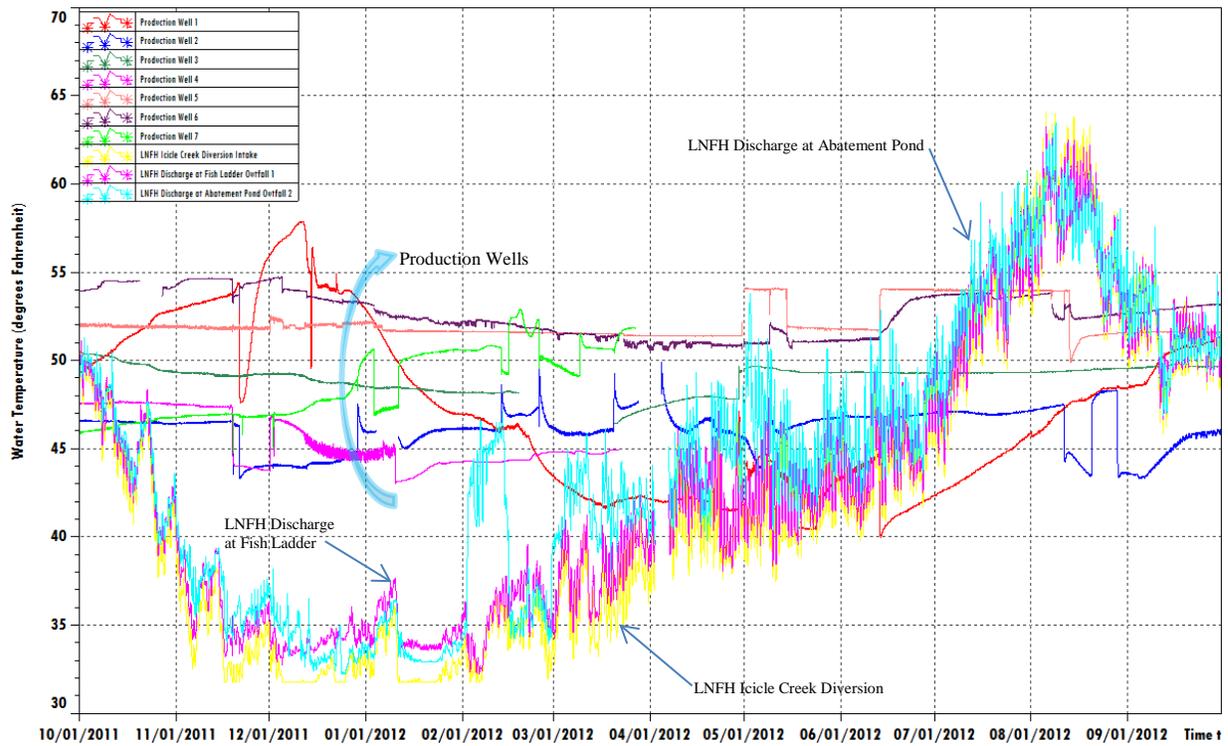


Figure 21. Hourly water temperature (degrees F) for LNFH Discharge at Abatement Pond (cyan), LNFH Discharge at Fish Ladder (magenta), LNFH Icicle Creek Diversion (yellow), Production Wells; 1 (red), 2 (blue), 3 (green), 4 (pink), 5 (peach), 6 (purple), and 7 (light green).

Flow-averaged temperature is calculated using a technique that assumes temperature is a conservative tracer and there is no loss or gain of mass. The equation to calculate flow averaged-temperature is shown in equation 5.

Equation 5.

shown in the red line of figure 22. The difference between the outfall sites, LNFH Discharge at Fish Ladder or LNFH Discharge at Abatement Pond, and flow-averaged temperature is on the right y-axis of figure 22. Flow-averaged temperature is different from the LNFH Discharge at Fish Ladder site (dark green line) by approximately +/- 1 degrees Fahrenheit, and minus 2 degrees Fahrenheit during the nursery effluent release in February. In contrast to water year 2011, LNFH Discharge at Fish Ladder temperatures span both above and below flow-average temperatures with an average difference of -0.10 from the calculated flow-averaged temperature. Only the summer month data was available in water year 2011 to calculate flow-averaged temperature, whereas the opposite winter month data is available to water year 2012. Flow-averaged temperature ranges between 0 and 15 degrees Fahrenheit less than the LNFH Discharge at Abatement Pond site (light green line). The difference between the calculated flow-averaged temperature and the temperatures of the LNFH Discharge at Abatement Pond indicate that LNFH operation and the Pollution Abatement Pond increases the temperature of water released to Icicle Creek.

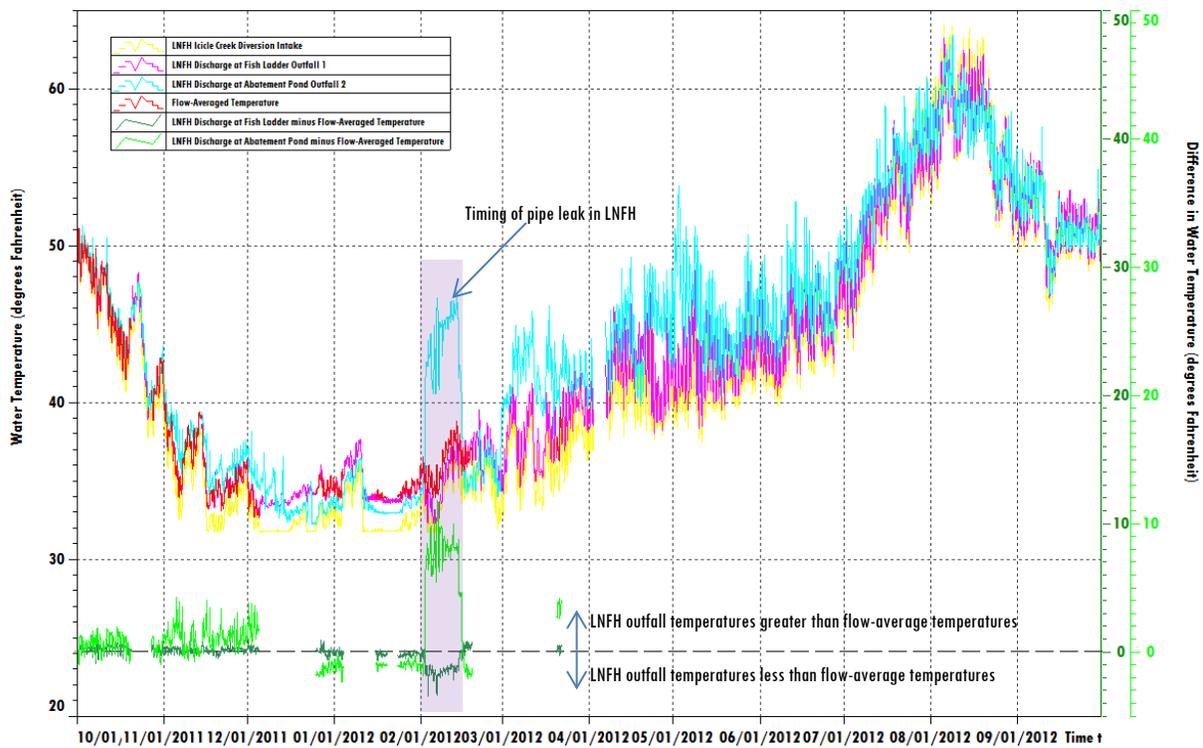


Figure 22. Hourly water temperature (degrees F) for LNFH Discharge at Abatement Pond (cyan), LNFH Discharge at Fish Ladder (magenta), LNFH Icicle Creek Diversion (yellow), flow-averaged temperature (red), the difference between LNFH Discharge at Fish Ladder and flow-averaged temperature (dark green), and the difference between LNFH Discharge at Abatement Pond and flow-averaged temperature (light green).

SUMMARY

Changes in discharge measured at Icicle Creek at Structure 2 and LNFH Channel at Spillway sites correspond with the discharge measured at the USGS and Ecology stream gaging sites on Icicle Creek , upstream and downstream, respectively, of the LNFH. The lowest flows over the LNFH Channel at Spillway correspond with 830 cfs at the Icicle Creek at Structure 2 site. Discharge out of the Snow Lakes Outlet site started on July 31, 2012. These flows out of the Snow Lakes are observed at the Snow Creek Mouth site. The combined discharge from the Production Wells adds approximately 5 to 10 cfs of inflow, approximately 11% to 19% the total supply, to the LNFH. LNFH Icicle Creek Diversion and LNFH Discharge at Fish Ladder sites require further investigation to obtain quality assurance of data. For example, to determine the quantity of flow to the LNFH after measurement at the LNFH Icicle Creek Diversion site the water returning to Icicle Creek through the overflow spillway at the intake house and diversions to COIC will need to be measured. Assuring accuracy of flow measurements out of the LNFH Discharge at Fish Ladder site will require determining submerged flume water depths as well as the ability to check water depths in flume and stilling well. The assurance of quality data from Snow Lakes Outlet and Snow Creek Mouth will continue with investigations into flow measured at the Nada Lake site. Flow-averaged temperature analysis shows that operations at the LNFH do increase and decrease temperatures of the inflow water used by the LNFH.

REFERENCES

Ecology, 2011, Washington State - Department of Ecology, River and Streamflow Monitoring Network.

<https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=45B070#block0>.

Ruhl, C.A., and Simpson, M.R., 2005, Computation of discharge using the index-velocity method in tidally affected areas: U.S. Geological Survey Scientific Investigations Report 2005-5004, 31 p.

S.E. Rantz, et al. 1982. Measurement and Computation of Streamflow: Volume 1.

Measurement of Stage and Discharge. U.S. Geological Supply Water-Supply Paper 2175

Sverdrup Civil Inc. (Sverdrup). 2000, Hydraulic and Hydrologic Analysis of Icicle Creek

Fish Passage Restoration Alternatives. Unpublished Report to ENSR International.

USGS, 2011, United States Geological Survey, National Water Information System.

http://waterdata.usgs.gov/wa/nwis/dv/?site_no=12458000&agency_cd=USGS&referred_module=sw